



This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

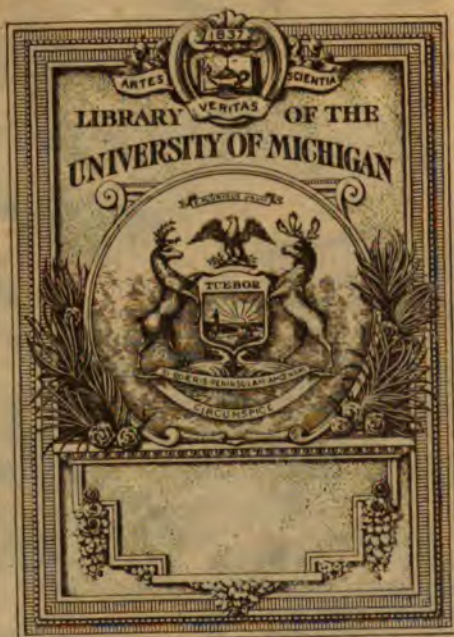
Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

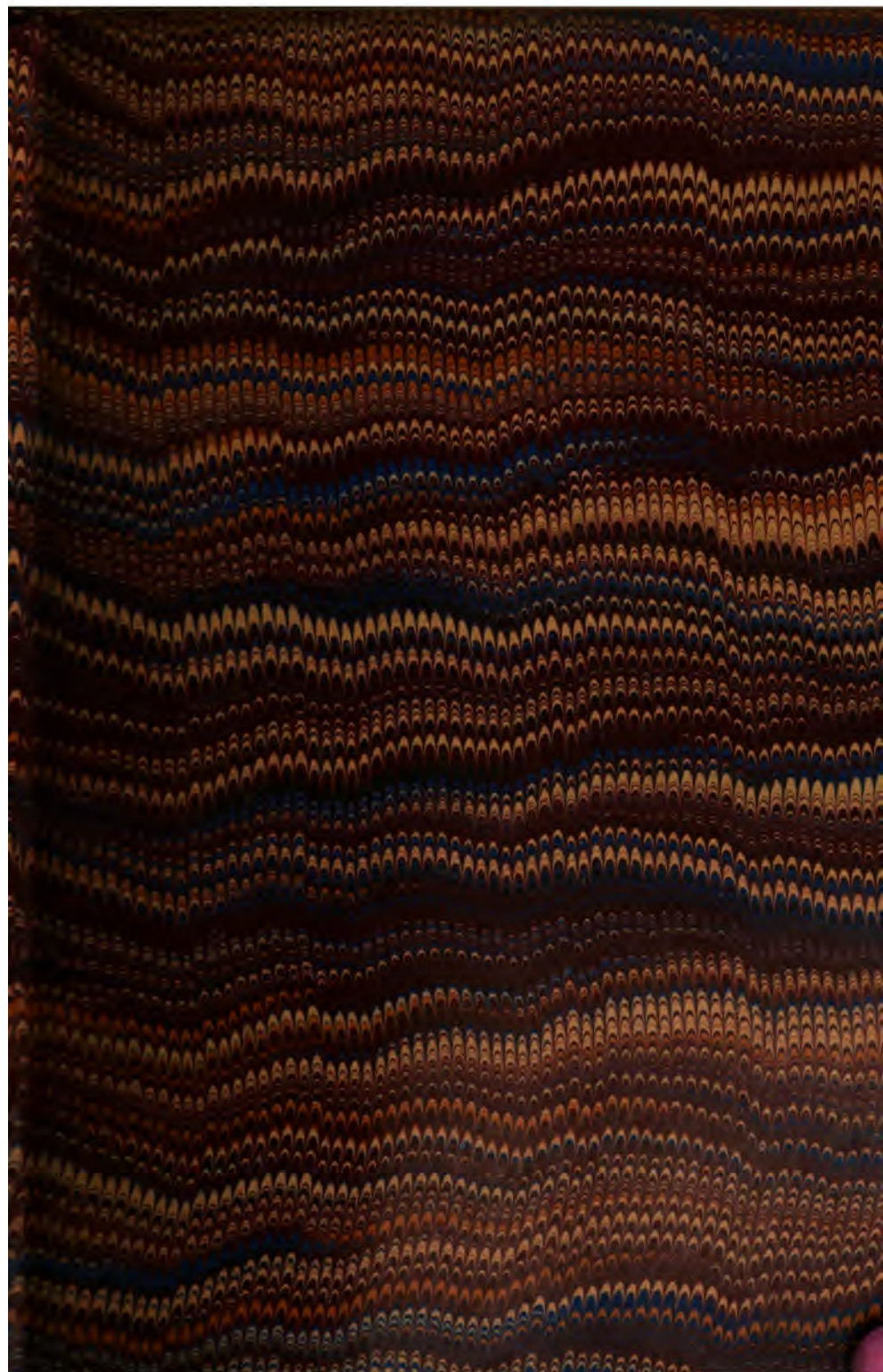
We also ask that you:

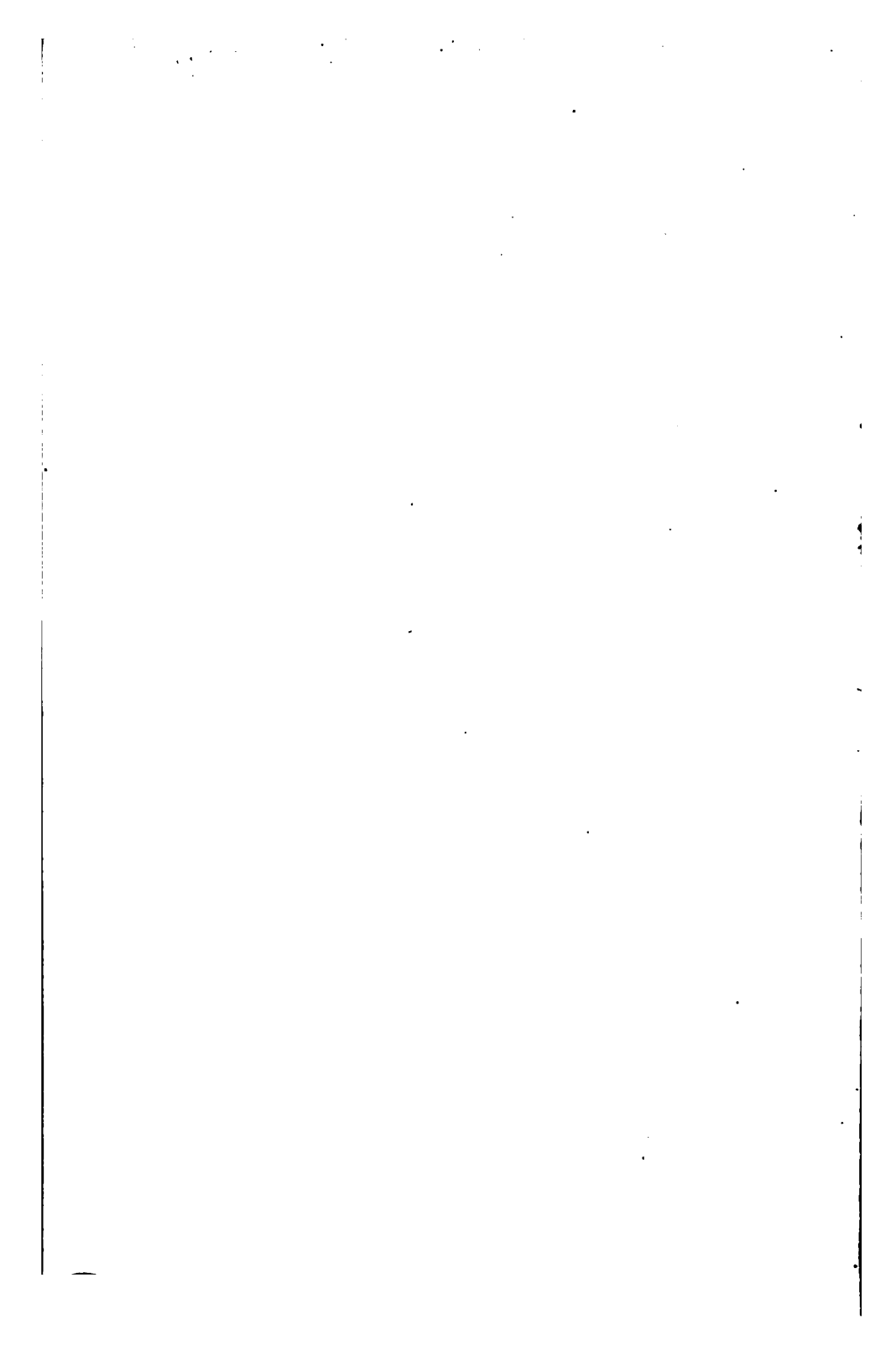
- + *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.
- + *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.
- + *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.
- + *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at <http://books.google.com/>







SCIENCE LIB.

S

218

.H.3

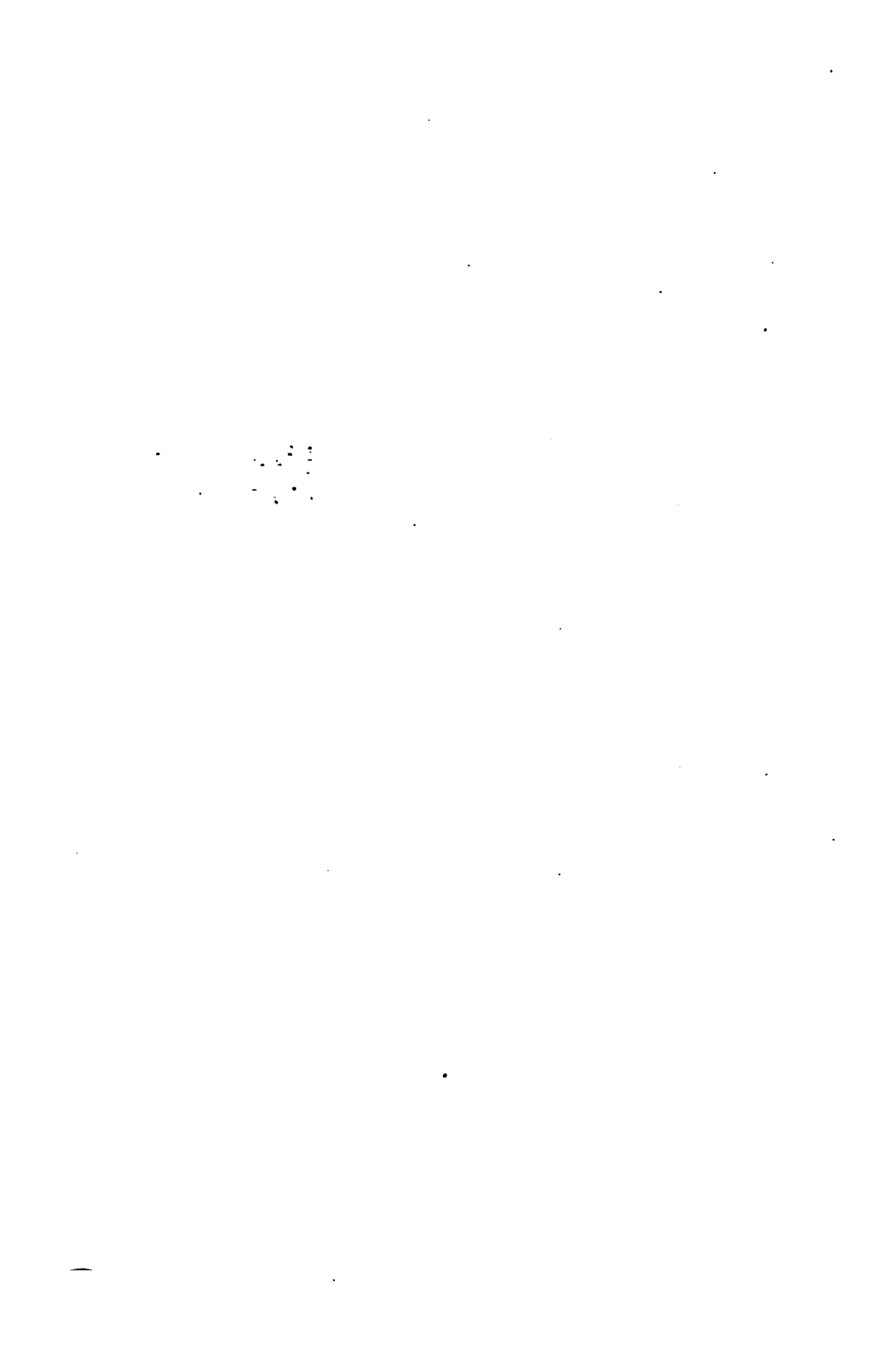
THE
ROTHAMSTED MEMOIRS
ON
AGRICULTURAL CHEMISTRY
AND
PHYSIOLOGY.

BY
SIR JOHN BENNET LAWES, BART., D.C.L., LL.D., F.R.S., F.C.S., &c.,
OF ROTHAMSTED, HERTS.,
AND
SIR JOSEPH HENRY GILBERT, M.A., PH.D., LL.D., F.R.S., V.P.C.S., &c.

VOLUME III.
CONTAINING REPORTS OF
FIELD EXPERIMENTS,
EXPERIMENTS ON VEGETATION,
&c., &c.

PUBLISHED 1863—1874 INCLUSIVE.

LONDON:
PRINTED BY WILLIAM CLOWES AND SONS, LIMITED,
STAMFORD STREET AND CHARING CROSS.
1893.



ROTHAMSTED MEMOIRS.

CONTENTS OF VOL. III.

REPORTS OF FIELD EXPERIMENTS, EXPERIMENTS ON VEGETATION, &c., &c.

	Published
1. On the Sources of the Nitrogen of Vegetation, with special reference to the question whether Plants assimilate free or uncombined Nitrogen (Jour. Chem. Soc., New Series, vol. i., Entire Series, vol. xvi., p. 100.)	1863
2. Liebig and the "Mineral Theory" (Note—extracted from a paper by J. B. Lawes and J. H. Gilbert—Jour. Roy. Ag. Soc. Eng., vol. xxiv., part 2, p. 506.)	1863
3. Further Report of Experiments with different Manures on Permanent Meadow Land (Jour. Roy. Ag. Soc. Eng., vol. xxiv., part 2, p. 504.)	1863
4. Report of Experiments on the Growth of Wheat, for Twenty Years in Succession on the same Land (Jour. Roy. Ag. Soc. Eng., vol. xxv., part 1, p. 93, and part 2, p. 449.)	1864
5. On the Selection of Artificial Manures for the Sugar Cane	1864
6. On the Accumulation of the Nitrogen of Manure in the Soil.—Abstract (Report of the British Association for the Advancement of Science for 1866)	1866
7. Preliminary Notice of Results on the Composition of Wheat grown for Twenty years in succession on the same Land (Report of the British Association for the Advancement of Science for 1867)	1867
8. On the Home-produce, Imports, and Consumption of Wheat (Jour. Roy. Ag. Soc. Eng., vol. vi., s. s., part 2, p. 359.)	1868
9. Exhaustion of the Soil in relation to Landlords' Covenants, and the Valuation of Unexhausted Improvements (Read before the London Farmers' Club, April 4, 1870)	1870
10. Scientific Agriculture with a view to Profit (Read before the Maidstone Farmers' Club, Dec. 15th, 1870)	1870
11. Effects of the Drought of 1870, on some of the Experimental Crops at Rothamsted (Jour. Roy. Ag. Soc. Eng., vol. vii., s. s., part 1, p. 91.)	1871
12. Notes on Clover Sickness (Jour. Roy. Hort. Soc., vol. iii.)	1871
13. Report of Experiments on the Growth of Barley, for Twenty Years in Succession on the same land (Jour. Roy. Ag. Soc. Eng., vol. ix., s. s., part 1, p. 89, and part 2, p. 275.)	1873
14. Unexhausted Tillages and Manures, with reference to the Landlord and Tenant (Ireland) Act, 1870	1874



ON THE
SOURCES OF THE NITROGEN OF VEGETATION;
WITH
SPECIAL REFERENCE TO THE QUESTION WHETHER PLANTS
ASSIMILATE FREE OR UNCOMBINED NITROGEN.

LONDON:
PRINTED BY HARRISON AND SONS, ST. MARTIN'S LANE, W.C.
1863.

REPRINTED BY SPOTTISWOODE & CO., NEW-STREET SQUARE.
1895.

[Reprinted from the *Journal of the Chemical Society*, 1863.]

On the Sources of the Nitrogen of Vegetation; with special reference to the question whether Plants Assimilate Free or Uncombined Nitrogen.

By J. B. LAWES, F.R.S., F.C.S.; J. H. GILBERT, Ph.D., F.R.S., F.C.S.; and EVAN PUGH, Ph.D., F.C.S.*

WITH our present knowledge of the general composition of plants, and of the sources of their constituents, it is easy to see how essential was a proper understanding of the chemistry of the air, and of water, to any true conception of the material changes involved in the vegetative process. It was in fact between 1770 and 1800, that Black, Scheele, Priestly, Lavoisier, Cavendish, and Watt, were engaged in establishing that common air consists chiefly of nitrogen and oxygen, with a little carbonic acid,—that carbonic acid is composed of carbon and oxygen,—and water of hydrogen and oxygen;—and it was within the same period, that Priestly and Ingenhousz, Sennebier and Woodhouse, laboured to show the mutual relations of these bodies and vegetable growth. They seem, however, to have had more prominently in view the question of the influence of plants upon the media with which they were surrounded, than that of the influence of those media in contributing to the increased substance of plants themselves.

Following closely on the footsteps of the above observers, both

* This paper is in the main an abstract of a full report, under the same title in the *Philosophical Transactions*, part ii, 1861.

in point of time and general plan of research, came De Saussure, whose labours were conducted towards the end of the last, and in the beginning of the present, century; and their results, together with the arguments founded upon them, were published by him in 1804. To De Saussure we owe the experimental, and even quantitative, illustration of the fact, that plants, in sunlight, increase in their amounts of carbon, hydrogen, and oxygen, at the expense of carbonic acid and of water. Indeed, he concluded that air and water contributed a much larger proportion of the dry substance of plants, than did the soils in which they grew.

Besides carbon, hydrogen, and oxygen, plants had already been shown to contain *nitrogen*. Priestly and Ingenhousz thought they had observed that plants absorbed the free nitrogen of the confined atmospheres in which they were placed in their experiments. Sennebier and Woodhouse arrived at an opposite conclusion. De Saussure, again, thought that his experiments indicated rather an evolution of nitrogen at the expense of the substance of the plants, than any assimilation of it from that supplied in the free and gaseous form. In fact, he concluded that the source of the nitrogen of plants was, more probably, the nitrogenous compounds in the soil, and the small amount of ammonia which he demonstrated to exist in the atmosphere.

De Saussure further maintained the essentialness of the incombustible constituents of plants, and pointed out that they were derived from the soil. In his view, the fertile soil was the one which yielded liberally to the plants, nitrogenous compounds, and the incombustible or mineral constituents. He also called attention to the probability that the incombustible or mineral constituents of plants were the source of those found in the animals fed upon them.

Although there still remain to be solved, questions of vast scientific as well as practical interest regarding the conditions under which different plants take up their carbon, hydrogen, and oxygen, yet those who devote themselves to agricultural chemistry soon find that the explanation of the chemical phenomena of agricultural production awaits much more for a further elucidation of the sources, and modes of assimilation, of their *nitrogen*.

In 1837, Boussingault took up the subject of the sources of the nitrogen of plants, where De Saussure had left it more than thirty years before; being apparently led to see the importance of a further investigation of the question by a consideration of the

chemical statistics of certain agricultural practices on the large scale.

To the investigations and conclusions of Boussingault, and others, reference will be made further on; but before doing so, or entering upon the consideration of our own experimental evidence regarding the assimilation of nitrogen by plants, attention will be called to a few prominent and striking facts established here, at Rothamsted, illustrative of the amounts of nitrogen yielded by different crops over a given area of land, and of the relation of these to certain measured, or known, sources of it.

I.—Annual yield of Nitrogen per Acre in different Crops.

The following summary table shows the average annual yield of nitrogen per acre, in the respective crops, when each was grown year after year on the same land, without manure, or with mineral, but without nitrogenous manure.

TABLE I.

Crop.	Seasons.	No. of years.	Nitrogen per acre per annum. lbs.
Wheat	1844—1859	16	24·4 without manure.
Barley	1852—1859	8	24·7 " "
Beans.....	1847—1858	12	47·8 " "
Meadow-Hay ...	1856—1862	7	39·7 " "
Turnips	1845—1853	8	42·0 with mineral manure.

In each case, the land was, in an agricultural sense, exhausted before the commencement of the experiment; that is to say, it would, in ordinary practice, have required manure before growing another crop.

It is seen that, without manure, the two Gramineaceous crops (wheat and barley) gave an average of about 24½lbs. nitrogen per acre per annum; the Leguminous crop (beans) nearly twice as much, or 47·8lbs., and the mixed herbage of the meadow-hay, comprising both Gramineaceous and Leguminous plants, 39·7lbs. Lastly, the turnips, with mineral, but without nitrogenous manure, gave 42lbs.

In reference to these results it should be stated, that the wheat as yet shows little, if any, but the barley with its more superficial range of roots, more obvious indication of progressive decline in the

annual yield; and at present the meadow land shows no signs of diminution of produce. The yield of the Leguminous crop (beans), on the other hand, has depreciated very considerably, the average annual yield of nitrogen over the first six years being 70lbs., and that over the concluding six years only 26lbs. The turnips, again, appeared to have greatly exhausted the immediately available nitrogen in the soil, within the range of collection of the barley plant; for, on barley succeeding the eight mineral-manured turnip crops, the produce was only about three-fourths as much as that obtained, in the same season, where barley was grown the second year in succession without manure, and only about three-fifths as much as where barley was grown as the second crop, of the second course, in a series of entirely unmanured four-course rotation-crops.

It should be further explained, that turnips, grown year after year without manure of any kind, yield, after a few years, only a few cwts. of produce per acre; that purely Gramineous crops have given very little gain in the annual yield of nitrogen by the use of mineral without nitrogenous manures; but that Leguminous crops, like the turnips just referred to, have given a considerably increased crop, and yield of nitrogen, under the influence of purely mineral manures.

In further illustration of the larger amount of nitrogen yielded over a given area in Leguminous than in Gramineous crops, the following remarkable results may be cited. Red clover was grown in three out of four consecutive years—the intermediate crop being wheat—all without manure:—

TABLE II.

Season.	Crop.	Nitrogen per acre. lbs.
1st year, 1849	Clover	206·8
(2nd year, 1850	Wheat	45·2)
3rd year, 1851	Clover	29·3
4th year, 1852	Clover	111·9
Average of the three years' clover ...		116·0

All further attempts to grow clover, year after year, on this land, have, however, failed. Neither ammonia-salts, nor organic matters rich in carbon, nor mineral manures, nor mixtures of all,

have availed to restore the clover-yielding capabilities of the land. On the other hand, it should be particularly observed that, after taking 206·8lbs. of nitrogen from an acre in the clover crop of the first year, the wheat crop of the succeeding year was about double that obtained in the same season on a plot which had grown the crop for a series of years without manure, and equal to that obtained where during the same period farm-yard manure had been annually applied.

The following table shows the amount of nitrogen obtained per acre in wheat grown consecutively, in wheat alternated with beans, and in wheat alternated with fallow :—

TABLE III.

Period of Experiment ten years, 1850–9 inclusive.

			Nitrogen per acre. lbs.	
			Total.	Average annual.
Beans	} ten crops consecutively	{ Without manure	346·9	34·7
		{ With mineral manure	510·6	51·1
Wheat	} without manure	{ 10 crops consecutively	234·0	23·4
		{ 5 crops alternated with fallow	219·3	43·9 or 21·9
Wheat	} without manure	{ 5 crops alternated with beans	225·8	45·2 or 22·6
		{ 5 crops alternated with wheat	244·5	48·9 or 24·5
Wheat	} with mineral manure	{ 5 crops alternated with beans	207·0	41·4 or 20·7
		{ 5 crops alternated with wheat	227·2	45·4 or 22·7

The general result is seen to be, that pretty nearly the same amount of nitrogen was taken from a given area of land in wheat, in ten years, whether ten crops were grown consecutively, five in alternation with fallow, or five in alternation with beans. In fact, the crop of wheat was increased fully as much when it succeeded beans, which *carried off* a large amount of nitrogen, and of mineral matter also, as when it succeeded fallow, which *conserved and increased* the immediately available stores both of nitrogen and of mineral matter. It is also a remarkable fact, that *adding nitrogenous manures* is found to have much the same effect in increasing the produce of the wheat crop.

It will be seen by the illustrations next given, that the experimental results thus far adduced are consistent with those obtained

under circumstances more nearly allied to those of ordinary farm practice.

Taking the results of six separate courses of rotation, Bous-singault obtained an average of between one-third and one-half more nitrogen in the produce than had been supplied in manure. His largest yields of nitrogen were in the Leguminous crops; and the cereal crops were the larger, when they next succeeded the removal of the highly nitrogenous Leguminous crops.

In the experiments on this point at Rothamsted, the four-course rotation of turnips, barley, Leguminous crop (or fallow), and wheat, has been followed for twelve years—that is, through three separate courses,—*without manure*,* and the average annual yield of nitrogen per acre was 42·6lbs. The second and third courses gave, however, much less than the first, and hence, a smaller average per annum than that stated for the twelve years; the reduction being due to the falling off in the produce of the turnips, and of the Leguminous crop, whilst that of the barley and wheat has hitherto been fully maintained. The average yield of the twelve years is nearly twice as much as was obtained in wheat or barley, grown year after year, on the same land, without manure; and that of the last eight years even is considerably greater than the amount so obtained. The greatest yield of nitrogen was in the clover, which constituted the Leguminous crop of the first course; and the wheat-crops obtained after this clover, and after the beans in the second and third courses, were about double as much as the average where wheat has been grown succeeding wheat without manure, and about equal to the average obtained by farm-yard manure every year, or when wheat was grown after fallow, or after beans in the experiments last referred to.

The general result is, that, when grown year after year on the same land without manure, Gramineous crops gave about 24½lbs. of nitrogen per acre per annum, and Leguminous crops much more. Nevertheless, the Gramineous crop was nearly doubled when preceded by a Leguminous one; and it was also about doubled when preceded by fallow. Lastly, a series of entirely unmanured rotation-crops yielded considerably more nitrogen than the continuously grown unmanured Gramineous crops.

Further, the highly nitrogenous Leguminous crops were found

* The 16th crop, that is the last crop of the 4th course, is now growing, March, 1863.

to be comparatively little benefited by the direct application of nitrogenous manures in the form of ammonia-salts (though they are more so by nitrates), but considerably by mineral manures; whilst the cereals (wheat and barley), which yield a comparatively small amount of nitrogen, were much increased, both in amount of crop and yield of nitrogen per acre, by nitrogenous, but very little by mineral manures.

But, when the growth of crops (particularly the cereals) is increased by the direct application of nitrogenous manures, the increased yield of nitrogen over a series of years, bears a comparatively small proportion to the amount supplied in manure, as the following results will show:—

TABLE IV.

Crops.	Number of years.	Increased Nitrogen in produce for 100 in Manure.
Wheat.....	6	43.0
Barley.....	6	42.5
Meadow-Hay.....	7	44.8

Thus, over a period of six years, the increased yield of nitrogen in the wheat crop (compared with that without manure) amounted to 43, and in the barley crop to 42½, per cent. of that supplied in manure; and it should be added, that the remainder does not appear to exist in the soil available for an immediately succeeding crop: for it has frequently been found that when an increased yield of nitrogen has been obtained in the season of application equal to about 40 per cent. of that supplied, the increase in the succeeding year, even with the aid of mineral manures, has only been equal to about one-tenth of the remainder.

In the case of the mixed herbage of the permanent meadow, the increased yield of nitrogen was slightly higher in proportion to that supplied than with the cereals. In Leguminous crops it is found to be even somewhat less; whilst root-crops (turnips) seem to gather up nitrogen in somewhat larger proportion to that supplied.

Let it be assumed that the increased yield of nitrogen approximately represents the proportion of that supplied by manure which is recovered in the crop, and the question arises what becomes of the unrecovered amount?

It may in part be drained away and lost. The nitrogenous

compounds may be transformed within the soil, and their nitrogen, in some form, evaporated; or they may for the most part remain in the soil in some fixed combination, to be yielded up only in the course of a long series of years. Ammonia, or nitrogen in some form, may be given off from the surface of the growing plant. Or there may be simply an unfavourable distribution of the supplied nitrogen within the soil for the immediate crop; and the Leguminous crop, alternating with the Gramineous one, may gather from a more extended range, and leave a residue, or allow the accumulation, of assimilable nitrogen within the range of collection of the crops which succeed it.

These considerations lead us to the next branch of our subject, namely—

II.—*The actual or possible Sources of the Nitrogen of our Crops.*

The following actual or possible sources of the nitrogen of our crops, beyond that supplied in manure, may be enumerated:—

1. The nitrogen in certain constituent minerals of the soil, especially the ferruginous and aluminous, and certain nitrides.

2. The combined nitrogen annually coming down in the aqueous depositions of the atmosphere:—(a) as ammonia; (b) as nitric acid; (c) as organic corpuscles, &c.

3. The accumulation by the soil of combined nitrogen from the atmosphere:—(a) by surface absorption aided by moisture; (b) by the chemical action of certain mineral constituents of the soil; (c) by the chemical action of certain organic compounds in the soil.

4. The formation of ammonia, in the soil or the atmosphere, from free nitrogen (the so-formed ammonia either remaining as such, or being oxidated into nitric acid).

5. The oxidation of free nitrogen:—(a) by electric action; (b) with common oxygen, in contact with porous and alkaline substances; (c) under the influence of ozone, or nascent oxygen; (d) under that of evaporation, and combustion, as recently supposed by Schoenbein—ammonia at the same time being formed.

6. The direct absorption of combined nitrogen from the atmosphere by plants themselves.

7. The assimilation of free nitrogen by plants.

A very few observations may be offered on each of these actual or possible sources of the nitrogen of vegetation.

(1.) The combined nitrogen of certain of the constituent minerals

from which soils are derived, cannot be considered an adequate source of the nitrogen annually carried off in the vegetable produce of the land.

(2.) The combined nitrogen coming down in the aqueous deposits of rain, hail, snow, mists, fog, and dew, part of which is the return from previously existing generations of plants or animals elsewhere, and part the product of new formation, does undoubtedly contribute materially to the annual yield of nitrogen in our crops; and being a source comparatively easily estimated, it has been the subject of a good deal of experimental investigation; more particularly by Boussingault, Barral, Way, and two of ourselves, and by others on a more limited scale.

The following table shows the amount of nitrogen coming down as ammonia and nitric acid in the total rain, hail, snow, and some of the minor deposits, during the years 1853, 1855, 1856, here at Rothamsted, the nitric acid being in all cases determined by Mr. Way, and the ammonia in some cases by him, and in others by ourselves.

TABLE V.

	Nitrogen per acre, per annum. lbs.			
	1853.	1855.	1856.	Mean.
As ammonia.....	5.67	5.86	7.85	6.46
As nitric acid	(not determined.)	0.77	0.73	0.75
Total		6.63	8.58	7.21

It is seen that the available combined nitrogen so estimated, is competent to supply but a small proportion of that annually removed from an acre of land in different crops. Nor does it appear, from the results of Boussingault, that the amounts of combined nitrogen deposited by dew are such, that were correction made for the larger proportion so received by the soil, or the vegetation covering it, than was included in our collected and analysed aqueous deposits, any material modification in our approximate estimates would be required.

(3.) The amounts of combined nitrogen accumulated by the soil from the atmosphere, by surface absorption, or chemical action (whether due to restoration or to new formation), probably constitute a considerable proportion of that annually available for vegetation over a given area. Numerous investigations have been

undertaken, by ourselves and others, to determine the capacities for absorption of different soils, or constituents of soils; but, unfortunately, quantitative results obtained in the laboratory do not admit of direct and certain application to the estimation of the amount of combined nitrogen so fixed to a given depth, over a given area, within a given time.

(4 and 5.) The circumstances of the formation of ammonia, or of oxides of nitrogen, from gaseous, dissolved, or nascent nitrogen, are at present the subject of much conflicting statement; the various assumed actions being, as yet, by no means all clearly established qualitatively, and still less quantitatively. Moreover, here again, laboratory results would be difficult of application to the estimation of the probable amount of the nitrogen of vegetation due to such sources. To some of the actions in question further reference will, however, be made.

(6.) There is little of either qualitative or quantitative evidence in reference to the absorption of ammonia, or other compounds of nitrogen, from the air by plants themselves. Some vegetable physiologists, indeed, maintain that the leaves of living plants have not the function of absorption from the atmosphere, but only the converse one of evolution into it. Still, a few observations may be offered in connexion with the point in question.

Ripened cereal crops (wheat or barley) contain 1 part nitrogen to about 30 carbon, and Leguminous crops (beans, &c.) 1 part nitrogen to 15 or fewer of carbon. The atmosphere contains about 1 part carbon as carbonic acid to 10,000 of air; and it may be assumed, for illustration, to contain not more than 1 part nitrogen as ammonia to 12,000,000 of air;* or 1,200 times less nitrogen as ammonia than carbon as carbonic acid.

On these assumptions the ambient atmosphere contains a proportion of nitrogen as ammonia to carbon as carbonic acid, 40 times less than that of nitrogen to carbon in cereal produce, and 80 times (or more) less than that in Leguminous produce.

Hence, in point of *actual quantity merely*, the ammonia in the atmosphere would seem very inadequate to yield nitrogen in a degree corresponding to the yield of carbon by carbonic acid; nor does it appear, from observations hitherto recorded, that the nitrogen existing in the atmosphere, in combination with oxygen, would add much to that existing as ammonia.

* The amounts recorded by different observers range from 20.75 to 0.021 ammonia per million of air.

But water would absorb very much more nitrogen as ammonia, or dissolve very much more as carbonate or bicarbonate of ammonia, than it would of carbon as carbonic acid, under equal circumstances. In illustration, it may be mentioned that water at 60° F. (about 15·5 C.), would, at the normal pressure, absorb about 850 times as much nitrogen in the form of ammonia as carbon in carbonic acid; and, under equal circumstances, very many times more nitrogen as carbonate or bicarbonate of ammonia would be dissolved, than there would be of carbon as carbonic acid absorbed. There would appear to be, then, a compensating quality for the small actual and relative amount of nitrogen as ammonia in the atmosphere, in the greater absorbability, or solubility, of the compounds in which nitrogen exists, than of the carbonic acid in which the carbon is presented. How far the proportion of the nitrogen to the carbon available from the atmosphere in the combined form, may be really thus influenced under the actual conditions of vegetation, is a question, the numerous and intricate bearings of which, we do not profess here to enter upon.

One or two further observations may, however, be made as to the bearing of the actual facts of agricultural production on the point under consideration. Thus, Gramineaceous crops certainly depend very materially upon combined nitrogen *within the soil*, but are comparatively independent of carbonic acid yielded by manure in the soil; whilst Leguminous crops are at any rate much less benefited by the direct application of nitrogenous manures, from which it might, perhaps, seem that they were more able to avail themselves of nitrogen supplied in some way by the atmosphere, and possibly by the aid of their green parts. Even should this be the case, it can hardly be to a greater *mere extent of surface above ground*, that the result is to be attributed. Thus, a bean and a wheat crop may yield equal amounts of dry matter per acre, but the bean-produce would contain 2 to 3 times more nitrogen, although approximate measurements show that the wheat plant offers a greater external superficies in relation to a given weight of dry substance, and, therefore, greater still, of course, to a given amount of nitrogen fixed. If, therefore, the bean can in some way assume more nitrogen from atmospheric sources than the wheat crop, the result must be due to *character and function*, rather than to mere extent of surface above ground. In connexion with this point it may be observed, more particularly with reference to the crops that are grown for their ripened seed, that

the Leguminous crops, however, generally maintain their green and succulent surface, in relation to a more extended period of the season of active growth, than do the Gramineous crops.

(7.) *Assimilation of free or uncombined Nitrogen by Plants.*—From the above brief review, it appears that those sources of combined nitrogen to plants which have as yet been quantitatively estimated, are inadequate to account for the amounts obtained in the annual produce of a given area of land beyond that attributable to previous manuring; whilst those which have not yet been quantitatively estimated (if even fully established qualitatively) offer many practical difficulties in the way of any such investigation of them as would afford results directly applicable to our present purpose. It seemed, therefore, desirable to endeavour to settle the question, whether or not that vast storehouse of nitrogen, the atmosphere, in which vegetation is seen to live and flourish, be of any measurable avail to the growing plant, so far as its *uncombined* nitrogen is concerned.

The settlement of this question would indicate the degree of importance to be attached to other points of inquiry. Were it found that plants generally, or some more than others, assimilated free nitrogen, much would be gained towards the explanation of certain chemical facts of agricultural production; it would be established that vegetation had the attribute of effecting chemical combinations with an element the most reluctant to associate itself with other bodies in obedience to laboratory processes, and apt to rid itself of connections once formed, in the most violent manner; and we should be able more satisfactorily to account for the large actual amount of combined nitrogen existing and circulating in land and water, in animal and vegetable life, and in the atmosphere.

Moreover, the question of the assimilation of free nitrogen by plants, has, of late years, been submitted to an immense amount of research by numerous experimenters, and from the results very different conclusions have been arrived at. Hence, too, it seems desirable, before entering upon the discussion of our own experimental evidence on the point, to pass in review the methods, results, and conclusions of others, more particularly those of M. Boussingault who questions, and of M. George Ville who affirms, the assimilation of free nitrogen by plants; and as, so far as we are aware, the experiments of these other investigators have as yet been only very briefly noticed in English Scientific Journals,

we propose to give a somewhat fuller account of them than would otherwise have been necessary or appropriate.

III.—*The researches of others, on the question of the assimilation of free Nitrogen by Plants, and some allied points.*

De Saussure, and his predecessors, sought to solve the question whether plants assimilate free or uncombined nitrogen, by determining the changes undergone in the composition of limited volumes of air by the vegetation of plants within them. Boussingault pointed out that their methods were not fitted to attain the end in view. The general plan instituted by himself, and adopted with more or less modification in most subsequent researches, was :—

To set seeds or plants, the amount of nitrogen in which was estimated by the analysis of carefully-chosen similar specimens.

To employ soils and water containing either no combined nitrogen, or only known quantities of it.

To allow the access, either of free air (protecting the plants from rain and dust), of a current of air freed by washing from all combined nitrogen, or of a fixed and limited quantity of air, too small to be of any avail so far as its compounds of nitrogen were concerned. And finally—

To determine the amount of combined nitrogen in the plants produced, and in the soil, pot, &c., and, so, to provide the means of estimating the gain or loss of nitrogen during the course of the experiment.

M. Boussingault's Experiments.

The following table gives a summary of the results of M. Boussingault's experiments from 1837—1858, inclusive, on the question of the assimilation of free nitrogen by plants ; also a brief reference to the conditions under which the results were obtained :—

TABLE VI.

Summary of the results of M. Boussingault's Experiments.

Plants.	No. of seeds.	Period of growth; weeks.	Notes.	Grammes.				
				Seeds or Plants.	Produce Dry.	Nitrogen		
						In seeds (or plants).	In Products.*	Gain or loss.
1837: Burnt soil; distilled water; free air; in closed summer-house.**								
Trefoil		8	Fine green, but meagre.	2.000	2.218	0.1100	0.1200	+0.0100
Trefoil		13	Much foliage, part withered.	2.000	2.288	0.1140	0.1580	+0.0420
Wheat	37	8	Weak and slender.	1.326	2.300	0.0430	0.0400	-0.0030
Wheat	46	13	Lower leaves dead.	2.018	4.266	0.0670	0.0600	+0.0030
1838: Conditions as in 1837. †								
Peas	5	14	Flowers and seed.	1.211	4.821	0.0460	0.1010	+0.0550
Trefoil (plants)	3	9	Flowered.	1.117	2.754	0.0830	0.0560	+0.0230
Oats (plants)	4	7	Ripe seeds.	1.889	3.484	0.0590	0.0530	-0.0060
1851 and '52: Washed and ignited pumice with ashes; distilled water; limited air; under glass shade; with carbonic acid. ‡								
Haricot, 1851	1	8	Nascent flowers.	0.780	1.870	0.0849	0.0840	-0.0009
Oats, 1851	10	8	Small pale leaves.	0.377	0.540	0.0078	0.0067	-0.0011
Haricot, 1852	1	13	Good growth.	0.630	0.890	0.0310	0.0189	-0.0021
Haricot, 1852	1	18	Open flowers.	0.618	1.180	0.0245	0.0226	-0.0019
Oats, 1852	4	11	Ears shooting.	0.139	0.440	0.0031	0.0030	-0.0001
1853: Prepared pumice, or burnt brick, with ashes; distilled water; limited air; in glass globe; with carbonic acid. ‡								
White lupin	2	6	Vigorous growth.	0.825	1.820	0.0480	0.0483	+0.0003
Do. do.	6	8	Very fine foliage.	2.202	6.730	0.1282	0.1248	-0.0036
Do. do.	2	7½	Very vigorous.	0.600	1.950	0.0349	0.0339	-0.0010
Do. do.	1	6	The finest obtained.	0.343	1.050	0.0200	0.0204	+0.0004
Do. do.	2	7	Very active growth.	0.686	1.530	0.0399	0.0397	-0.0002
Dwarf Haricot	1	9	Nascent flowers.	0.792	2.359	0.0354	0.0360	+0.0006
Do. do.	1	11	Open flowers.	0.665	2.800	0.0298	0.0277	-0.0021
Garden cress	3	15	{ 3 grew, flowered and	0.008	0.068	0.0013	0.0013	0.0000
	10		seeded; 10 died.	0.026				
White lupins	2	19	{ 2 to grow, 8 as manure;	0.637	5.760	0.1897	0.1897	-0.0130
	8		vegetation magnificent.	2.512				
1854: Prepared pumice with ashes; distilled water; current of washed air; and carbonic acid; in glazed case. §								
Lupin	1	9½	11 leaves, some blackish.	0.337	2.140	0.0196	0.0187	-0.0009
Dwarf Haricot	1	10	Open flowers.	0.790	2.000	0.0322	0.0325	+0.0003
Do. do.	1	13½	Ripened seeds.	0.748	2.947	0.0335	0.0341	+0.0006
Do. do.	1	16	1 small ripe seed.	0.758	2.940	0.0339	0.0339	-0.0010
Do. do.	2	14	3 ripe seeds.	1.510	5.150	0.0676	0.0666	-0.0010
Lupin	1	7	{ 1 to grow, 1 as manure;	0.210	1.730	0.0180	0.0334	-0.0022
Do.	1		very fine plant.	0.900				
Cress	42	11	{ 30 grew, 12 as manure;	0.100	0.533	0.0046	0.0052	+0.0006
			seeded.					

* In the case of the 1837 and 1838 experiments, the nitrogen "In Products" seems to have included only that in the plants; in all other cases that in plants and soil, or plants, soil, and pot.

** Ann. Ch. Phys., [3.] lxxvii, (1838).

† Ibid., lxxix.

‡ Ann. Ch. Phys., [3.] xli, (1854).

§ Ann. Ch. Phys., ser. [3.] xliii, (1855).

‡ Dry.

TABLE VI (*continued*).

Plants.	No. of seeds.	Period of growth; weeks.	Notes.	Grammes.				
				Seeds or Plants.	Produce, Dry.	Nitrogen.		
						In seeds (or plants).	In products.*	Gain or loss.
1851, '52, '53, and '54: Prepared soil, or pumice with ashes; distilled water; free air, under glazed cage.**								
Haricot (dwarf), 1851..	1	15	{ Flowered and one im- perfect seed.	0.780	2.170	0.0349	0.0380	+0.0031
Haricot, 1852	1	13	Flowered and a pod.	0.537	2.110	0.0213	0.0238	+0.0025
Do. 1853	1	11	7 fine flowers.	0.655	2.720	0.0293	0.0270	-0.0023
Haricot (dwarf), 1854..	1	10	4 fine flowers.	0.710	2.200	0.0318	0.0350	+0.0032
Lupin (white), 1855 ..	1	13	Very fine, 11 leaves.	0.368	1.585	0.0214	0.0256	+0.0042
Do. 1854	1	12	Vigorous throughout.	0.341	1.960	0.0199	0.0222	+0.0023
Do. 1854	2	8	8 leaves each.	0.630	2.180	0.0367	0.0387	+0.0020
Oats, 1852	4	15	Stems slender, ripe ears.	0.151	0.670	0.0031	0.0041	+0.0010
Wheat, 1853	5	15	{ 1 died; others 11 leaves each.	0.293	0.900	0.0064	0.0075	+0.0011
Garden cress, 1854	210	8	145 plants, each seeded.	0.500	2.225	0.0259	0.0272	+0.0013
1858: Nitrate of potash as manure. †								
Helianthus	2	13	Flowered.	0.116	1.168	0.0144‡	0.0130	-0.0014
	2	13	Flowered.	0.116	2.120	0.0255‡	0.0245	-0.0010

In Boussingault's experiments in 1837 and 1838, he grew his plants in burnt soil, watered them with distilled water, allowed free access of air, but kept them protected from rain and dust in a summer house. The tabulated results show that the dry substance of the produce was always much more than, and sometimes several fold that of the seeds sown, or plants planted, indicating therefore, considerable growth, and consequent gain of carbon, hydrogen, and oxygen. They also show that in the case of the Leguminous plants, trefoil and peas, there was a gain of nitrogen varying from 10 to 55 milligrammes in the several experiments; whilst in that of the Gramineaceous ones, wheat and oats, in one instance there was a loss, and in another a gain of 3 milligrammes; and in another a loss of 6 milligrammes of nitrogen.

M. Boussingault's conclusions from the above results were in substance as follow:—That certain plants seem adapted to take up nitrogen in the atmosphere, but that it was a question under what circumstances, and in what state, the nitrogen was fixed. He submitted—that the nitrogen might enter directly into the

* In the experiments of 1851, 1852, 1853, 1854, and 1858, the nitrogen "In Products" included that in plants and soil, or plants, soil, and pot.

** Ann. Ch. Phys., sér. [3] xliii. (1855).

† Compt. rend., xlvii. (1858).

‡ Nitrogen in seed and nitrate.

organism of the plant, provided its green parts were adapted to fix it; that it might be conveyed into the plant in the aërated water taken up by its roots; that there may exist in the atmosphere an infinitely small amount of ammoniacal vapour. He further suggested, that the gain of nitrogen beyond that supplied in manure, which he had observed in agricultural production, and which he thought came from the atmosphere, might be partly due to nitrate of ammonia produced by electric action and brought down by rain.

In 1851 and 1852, Boussingault confined his plants (in pots) in limited volumes of air under glass shades of about 35 litres' capacity, which rested in lutes of sulphuric acid, with tubes passing under for the supply of carbonic acid and water. Pumice-stone, coarsely powdered, washed, ignited, and cooled over sulphuric acid, served as soil, to which ash, from farm-yard manure and from seed of the kind to be sown, was added. In each year haricots and oats were grown, and the table shows that the haricots increased a good deal in dry substance, and in two out of three cases advanced to flowering, and some of the oats shot forth ears. There was, however, in every case, both with haricots (Leguminous) and oats (Graminaceous), a slight loss of nitrogen, varying from $\frac{1}{16}$ th of a milligramme to 2 milligrammes.

In 1853, the enclosing apparatus was a large globe or carboy of white glass, of 70—80 litres' capacity. At the bottom, prepared pumice stone (or burnt brick), and ashes, served as soil, which was watered with distilled water, and then the seeds were sown. The neck of the vessel was then closed with a cork, through a perforation in which a flask of carbonic acid was inverted, whose aperture, opening into the globe was somewhat contracted. Finally, access of air was excluded by bandages of caoutchouc which rendered the whole apparatus air-tight.

In such apparatus, M. Boussingault made five separate experiments with white lupins, all of which grew more or less luxuriantly, and gained considerably in dry substance; but in no case was there as much as a milligramme of nitrogen gained; in three out of the five cases there was a slight loss, in one instance amounting to .0036 gramme. Two experiments were made with dwarf haricots, in both of which the gain of dry substance was considerable, and in one nascent, and in the other open flowers were developed; but in one case there was a gain of only .0006 gramme, and in the other a loss of .0021 gramme of nitrogen.

In an experiment with garden cress, in which three seeds grew and ten served as manure, abundant seed was produced, but there was neither gain nor loss of nitrogen. Lastly, in an experiment with white lupins, in which two seeds were sown to grow, and eight served as manure, the vegetation was very fine; but there was a loss of $\cdot 013$ gramme of nitrogen, attributed by Boussingault to free nitrogen-given off in the decomposition of the organic matter supplied as manure. In such an apparatus, then, eight experiments were made with Leguminous plants, in most of which there was a loss rather than a gain of nitrogen.

To ascertain whether the limitation of growth in the closed vessels was due to the limitation in the amount of air, Boussingault sowed cress under otherwise equal conditions, but in a good soil, and the result was even more luxuriant growth than in a similar soil in the open air.

In 1854, Boussingault grew a number of pots of plants in a metal-framed glass case of 124 litres' capacity, through which, by means of an aspirator of 500 litres, he passed a current of air, washed first through sulphuric acid and then water. He also supplied carbonic acid, generally equal in amount to from two to three per cent. of the atmosphere of the apparatus; and distilled water was also supplied when needed. Prepared pumice, with ashes, served as soil.

Two pots of lupins, four of haricots, and one of cress, were grown in such an apparatus. The increase in dry substance was in all cases considerable; and in some cases flowers, and in others ripe seeds were developed. In no case was there a gain of nitrogen amounting to one milligramme; and in four out of the seven there was a slight loss, amounting, in one instance, where a lupin had served as manure, to $\cdot 0021$ gramme.

Here, then, with a current of air, and with Leguminous plants, in six out of seven experiments, there was, upon the whole, a loss rather than a gain of nitrogen.

In 1851, 1852, 1853, and 1854, contemporaneously with the three series of experiments last described, Boussingault grew plants, so covered with a glazed cage as to exclude rain, or any material amount of dust, but allowing the free access of the external air. Haricots, lupins, oats, wheat, and cress, were so grown. The vegetation was in most cases vigorous. In several cases flowers, and in some seeds, were developed. In only one case was there less combined nitrogen determined in the total products, than was

estimated to be supplied. In the nine other experiments there was a gain of nitrogen indicated, varying from $\cdot 001$ to $\cdot 0042$ gramme, which Boussingault attributed to organic corpuscles and ammonia in the atmosphere.

Boussingault considered that, bearing in mind the circumstances of the above experiments, the gain was in no case sufficiently great to justify the conclusion that free nitrogen had been assimilated.

M. Boussingault made various collateral experiments to control or explain his results.

Various substances after being ignited were exposed to the air for two or three days, and then the combined nitrogen in them determined. A kilogramme, respectively, of sand gave 0.5, of powdered brick 0.5, of powdered bone-ash 0.84, and of wood-charcoal 2.9 milligrammes of ammonia.

To estimate the influence of organic corpuscles in the atmosphere, a pot of burnt sand, with ashes, the whole moistened with water, was so arranged under a glazed cage as to allow the free access of air, and, after exposure for two and a half months, small spots of cryptogamic vegetation were visible on the sand, but the whole yielded only 0.74 milligramme of nitrogen.

Ashes, if imperfectly burnt, were found in some cases to contain cyanides, in some ferrocyanides, and in others nitrogen in some other condition.

Boussingault considered that the larger gain of nitrogen indicated in his early experiments in free air (in 1837 and 1838) than in the later ones, was partly due to the comparatively defective methods of analysis at the early date, and partly to the distilled water then used containing some ammonia; for he had since learned, in his analysis of rain and other waters, that the distillate from water containing minute quantities of ammonia, did not come over free from it until about two-fifths of the whole had been drawn off.

To get increased vigour of growth, to avoid the loss of nitrogen apparently due to the evolution of free nitrogen during decomposition when organic matter was used as manure, and to determine whether the nitrogen of nitrates be assimilable by plants, Boussingault has latterly made some experiments in which nitrates were employed as manure.

In 1855, Boussingault grew two pots of helianthus, one without nitrogenous manure, and the other with a small known

quantity of nitrate of potash supplied to the soil; also three pots of cress, one without nitrogenous manure, one with a manured soil, and one to the soil of which nitrate of soda was added. In the experiments with nitrogenous manure there was considerably increased assimilation of carbon, and much more nitrogen assimilated than was supplied by the seeds, but the excess was not equal to that supplied in the nitrate, where it was used.

Lastly, in 1858, Boussingault grew two separate pots of helianthus, using as soil sand and quartz, well washed and ignited, with the addition of nitrate of potash, in one case equal 0.0111, and in the other 0.0222 gramme nitrogen. In the first experiment there was 0.0014, and in the second 0.001 gramme less nitrogen found in the plant, soil, and pot, than was supplied in the seed and nitrate; and Boussingault supposed that nitrate had been decomposed in the soil by the organic matter of the debris of the seeds and the roots, and that nitrogen had been evolved.

From the results of these two experiments with nitrates, Boussingault concluded—that there was no assimilation of free nitrogen; that there was a loss of supplied nitrogen, either from the soil or by the plant; and that the amount of carbon assimilated bore a close relation to that of the nitrogen taken up by the plant.

The result is, then, that in Boussingault's experiments, extending over more than twenty years, and made under very varied conditions, neither with Leguminous plants nor others, did he find any assimilation of free nitrogen.

M. G. Ville's Experiments.

M. G. Ville, of Paris, commenced his investigations on the subject of the assimilation of free nitrogen by plants, in 1849.

He first determined the ammonia in the atmosphere by aspiring large quantities, over periods of several months, through acid. In this way he found the air of Paris to give a mean of 0.0237, and that of its suburbs 0.0211 part by weight of ammonia to 1,000,000 parts by weight of air.

In M. Ville's experiments on the assimilation of nitrogen by plants, he used specially-made porous flower-pots, washed and ignited sand, sand and brick, or sand and charcoal, as soil, adding to it ashes. For the most part, several pots were enclosed in an iron-framed glazed case of 150 litres' (or more) capacity, through

which a current of air, washed or unwashed, was aspirated. Carbonic acid and distilled water were supplied as needed. In some cases ammoniacal gas was passed into the air of the apparatus. In others nitrates, or ammonia-salts, were supplied to the soil, and then the plants had free access of air, only shaded from rain and dust.

The following table summarises the chief results of M. Ville on the question of the assimilation of nitrogen by plants:—

TABLE VII.

Summary of M. G. Ville's Experiments.

Plants.	Period of growth; weeks.	Notes.	Dry substance. Grammes.		Nitrogen.—Grammes.			Nitrogen in products to 1 supplied.
			In seed (or plants).	In produce.	In seed; and air or manure.	In products (plants only).	Gain or loss.	
1849: Current of unwashed air supplying 0·001 grm. Nitrogen as Ammonia.*								
Cress	9		0·531	8·733	0·0280	0·1470	0·1210	5·6
Large Lupins ..	9		0·991	3·508	0·0640	0·0640	0·0000	1·0
Small Lupins ..	9		0·991	3·565	0·0640	0·0470	-0·0170	0·7
					0·1550	0·2580	0·1030	1·7
1850: Current of unwashed air supplying 0·0017 grm. Nitrogen as Ammonia.*								
Colza (plants) ..	17		0·599	53·761	0·0260	1·0700	1·0440	41·1
Wheat	17		0·632	2·807	0·0160	0·0310	0·0150	1·9
Rye	17		0·617	3·136	0·0130	0·0370	0·0240	2·8
Maize	17		1·488	4·503	0·0290	0·1280	0·0990	4·4
					0·0837	1·2660	1·1803	14·8
1851: Current of washed air.*								
Sunflower	13	96 rudimentary grains.	0·184	35·586	0·0060	0·1570	0·1630	31·4
Tobacco	13		0·064	23·436	0·0040	0·1760	0·1710	43·7
Tobacco	13		0·064	30·780	0·0040	0·1630	0·1580	40·5
1852: Current of washed air.*								
Autumn Colza ..	37	Flowered.	0·854	27·412	0·0480	0·2360	0·1790	4·7
Spring Wheat ..	16	47 complete grains.	1·194	12·917	0·0290	0·0650	0·0360	3·2
Sunflower	30	413 rudimentary grains.	0·888	64·090	0·0160	0·4080	0·3920	25·5
Summer Colza ..	15	much leaf.	3·723	80·408	0·1730	0·5950	0·4220	3·4
Summer Colza ..	10	much leaf.	1·833	64·796	0·1060	0·7010	0·5960	6·7
1854: Current of washed air (under superintendence of a Commission).†								
Cress	10	Did not thrive.	0·218‡	3·243 †	0·0099	0·0097	-0·0002	1·0
Cress	10		0·124‡	6·021	0·0038	0·0630	0·0492	13·9
Cress	10		0·128‡	1·806	0·0039	0·0110	0·0071	2·6

* Recherches Expérimentales sur la Végétation, par M. Georges Ville. Paris, 1853.

† Compt. rend., 1855.

‡ Not dry.

TABLE VII (*continued*).

Plants.	Period of growth ; weeks.	Notes.	Dry substance. Grammes.		Nitrogen.—Grammes.			Nitrogen in products to 1 supplied.
			In seed (or plants).	In produce.	In seed ; and air or manure.	In products (plants only).	Gain or loss.	
1854 : Current of washed air (closed, under the superintendence of a Commission).*								
Cress	7		0·206†	3·599	0·0063	0·0350	0·0287	5·6
1855 and 1856 : In free air ; with 0·5 grm. Nitre = 0·069 Nitrogen.‡								
Colza	7		0·027	5·450	0·0700	0·0700	0·0000	1·0
Colza	7		0·027	5·140	0·0700	0·0660	-0·0040	0·9
Co'za	10		0·027	5·020	0·0700	0·0680	-0·0020	1·0
1855 and 1856 : In free air ; with 1 grm. Nitre = 0·138 Nitrogen.‡								
Colza	9		0·031	7·750	0·1400	0·1970	0·0570	1·41
Colza	13		0·031	15·300	0·1400	0·3740	0·2340	2·67
Colza	17		0·031	10·770	0·1400	0·2160	0·0760	1·54
Colza	18		0·031	22·230	0·1400	0·2600	0·1100	1·79
1856 : In free air ; with 0·792 grm. Nitre = 0·110 Nitrogen.‡								
Wheat	24			26·900	0·1260	0·2180	0·0920	1·7
Wheat	24			26·520	0·1260	0·2240	0·0980	1·8
1855 : In free air ; with 1·72 grm. Nitre = 0·238 Nitrogen.‡								
Wheat	26	Gave 84 grains.		87·370	0·2590	0·3080	0·0490	1·3
1856 : In free air ; with 1·766 grm. Nitre = 0·244 Nitrogen.‡								
Wheat	23	Flowered.		26·87	0·2650	0·2170	-0·0480	0·3
Wheat	29	Gave 119 grains.		41·56	0·2650	0·3500	+0·0850	1·3

In 1849, M. Ville placed three pots of plants in his apparatus, one of cress, one of large lupins, and one of small lupins ; sand was used as soil ; and the aspirated air was unwashed. The cress plants gave more than sixteen-fold the dry substance of the seed sown ; and about five and a half fold the nitrogen in the seed. The other plants did not gain nitrogen. The total nitrogen in the seed of the three pots was estimated at 0·154 gramme, that in the ammonia of the unwashed air 0·001, and that in the total products was 0·258, showing a gain in the three experiments

* Compt. rend., 1855.

† Not dry.

‡ Recherches Expérimentales sur la Végétation, 1857.

of 0.103 gramme, or 1.7 fold that supplied. M. Ville concluded that the cress had assimilated a considerable quantity of free nitrogen.

In 1850 four pots, one of colza, one of wheat, one of rye, and one of maize, were enclosed in the apparatus; and the conditions were the same as in 1849, excepting that the experiment with the colza commenced with young plants instead of seed. The produced colzas gave nearly 90 fold the dry substance of the young plants; and the nitrogen also increased more than forty-fold. The other plants also gained, but in less amount and proportion. The total combined nitrogen in the contents of the apparatus was nearly fifteen times that supplied, 1.18 gramme being gained. The conclusion was that a large quantity of free nitrogen had been assimilated.

In 1851 the plants were supplied with a current of air washed free from ammonia. One pot of sunflower, and two of tobacco (the latter starting from young plants), were grown together in the apparatus, with the conditions otherwise as before. The sunflowers gave 95 rudimentary grains, but the tobaccos did not flower. The three experiments together gave nearly two hundred-fold the original dry matter, and nearly forty-fold the original nitrogen, the actual gain in the apparatus being 0.481 gramme.

In 1852 the conditions were as in 1851, and the plants grown were autumn colzas (from plants), spring wheat (from seed), sunflower (from seed), and summer colzas (from plants). All gave a considerable increase of dry matter; and the total combined nitrogen gained in the apparatus was 1.624 gramme, or 5.3 times as much as was supplied in the original plants and seed.

In each of the years 1850, 1851, and 1852, M. Ville had a duplicate apparatus, with plants similar to those in the experiments above described, to which, however, he supplied ammonia in the atmosphere of the apparatus. These duplicate plants increased much more, both in dry substance and in nitrogen, than the others; but the gain of nitrogen was in no case equal to that supplied as ammonia, and hence, the results have not a direct bearing upon the question of the assimilation of free or uncombined nitrogen.

Up to 1853, inclusive, M. Boussingault had experimented either in free air, with protection from rain and dust, or in fixed and limited air, and, considering the conditions, in neither case was it concluded that free nitrogen had been assimilated.

M. G. Ville's experiments up to the same period, had, on the other hand, indicated an enormous gain of nitrogen. Results so strikingly contradictory, naturally excited great attention; but the fact that M. Boussingault's plants had not been supplied with a *current* of air, and some other circumstances, were alleged to account for the difference in result. In 1854, M. Boussingault commenced experiments with a current of air, the results of which have already been given, and a Commission of members of the Academy of Sciences of France, comprising MM. Dumas, Regnault, Payen, Decaisne, Peligot, and Chevreul, was appointed to superintend a new set of experiments by M. Ville.

M. Ville's experiments under the Commission were conducted at the Muséum d'Histoire Naturelle, Jardin des Plantes, Paris; M. Cloez was appointed to assist him, and M. Chevreul reported on behalf of the Commission in 1855. In one apparatus connected with the aspirator three pots of cress were placed, and in another smaller one (which was not opened during the experiment, as the other frequently was), one pot of cress was grown. In one pot, in the set of three experiments, there was no gain; in another a gain of 0.0492; and in the third, a gain of 0.0071 gramme of nitrogen. In the permanently closed apparatus there was a gain of 0.0287 gramme nitrogen.

Unfortunately, an element of uncertainty attached to these experiments under the Commission. A quantity of distilled water from the bulk used for watering the plants, was in course of evaporation with oxalic acid under the superintendence of M. Cloez, when he was called away for some days; and when M. Peligot determined the ammonia in the acid residue, and also in that of the water removed from the cases, he found such an excess of ammonia in the water before being used over that in the water removed from the larger case, as more than covered the increase of nitrogen in the experiments. But when new portions of the original water were examined, a different result was obtained; and M. Cloez found that the previous evaporation had, in his absence, gone on by the side of ammoniacal emanations. However, the result with the single pot, in the small apparatus, showed a considerable gain of nitrogen, even supposing the first analysis of the supplied water to be correct.

From the result of the whole inquiry, the Commission announced the following conclusion:—

That the experiment made at the Muséum d'Histoire Naturelle,

by M. Ville, is consistent with the conclusions which he has drawn from his previous labours.

In 1855 and 1856, M. G. Ville conducted experiments in which the plants were allowed to grow in free air, only shaded from rain, and of which the special conditions were, that nitrate of potash in smaller or in larger quantity, or nitrate of potash and different ammonia-salts, in equivalent quantities as to nitrogen contents, were employed. Artificial soils, with ashes of plants, and distilled water, being used as before.

With a view to these experiments, he devised a method for estimating minute quantities of nitric acid, which was favourably reported upon by M. Pelouze, on behalf of a Commission, composed of MM. Balard, Peligot, and himself.

In 1855 two pots, and in 1856 one pot, of colzas were grown, to each of which 0.5 gramme of nitre was supplied. The dry substance increased about two hundred-fold; and analysis showed that the total produce contained almost exactly the same amount of nitrogen as that supplied in the seed and the nitrate. In each of the same years two pots of colzas were grown, to each of which 1 gramme of nitre was supplied. The dry matter of the produce was several hundred times as much as that of the seed sown; and it contained considerably more nitrogen than had been supplied in the seed and nitrate. M. Ville concluded that when, by the larger supply of nitrate, the growth had been extended, free nitrogen was assimilated.

In 1855, a pot of wheat was grown manured with 1.72 gramme of nitrate of potash. Eighty-four grains were produced; and there was more nitrogen in the produce alone, than in the seed and nitrate, and much more when the residue in the soil was taken into account. In 1856, two pots of wheat were sown to each of which 1.765 gramme of nitre was added. The plants of one pot were taken up at the time of flowering, and found to contain almost as much nitrogen as was supplied in the seed and nitrate. Those in the other were left as seed, and gave 119 grains; and the nitrogen in the produce, exclusive of the residue in the soil and pot, was much more than that supplied. Also, in 1856, two pots of wheat were sown without nitrate, and two with 0.792 gramme each. The actual gain of nitrogen was the greater where the nitrate was employed, but the proportion gained, to that supplied, was greater where no nitrate was supplied.

In 1856, experiments were also made, comparing the effects of

nitrates and ammonia-salts, from the results of which it was concluded, that a given amount of nitrogen was more efficacious in the form of nitrate, than in that of ammonia-salts.

In regard to the experiments made in 1855 and 1856, in free air, with nitrates or ammonia-salts supplied, M. Ville remarks that the point at which the supplied nitrogen becomes exhausted is indicated by a lightening of the colour of the leaves, and that it is then that the plants begin to assimilate free nitrogen; to secure which it is necessary that the supply of nitrogen, and the vigour of growth, should reach a certain point, but that the supply should not exceed a certain limit. Further, that the gain of nitrogen in the experiments in question was so great, and the amount before shown to be available from atmospheric ammonia was so small, that the influence of that source may be entirely overlooked. He enumerates the following conclusions:—

1. By means of nitre we may prove, without the aid of an enclosing apparatus, that plants absorb and assimilate the gaseous nitrogen of the atmosphere.

2. Nitre acts by its nitrogen. It is absorbed in the state of nitre.

3. In relation to the amount of nitrogen, nitre is more active than ammonia-salts.

M. Ville also made various collateral experiments.*

Air was passed through an otherwise closed apparatus, in which was placed a vessel containing calcined sand, or calcined sand and decomposing organic matter, but in no case was nitric acid formed; hence, nitrification was not the source of the nitrogen gained by the experimental plants.

Given amounts of organic matter, lupins, gelatine, &c., were mixed with calcined sand, and exposed in an apparatus to a current of air which carried the gaseous products through acid. The determination of the nitrogen remaining in the matrix, and of that absorbed as ammonia by the acid, showed a loss of nitrogen given off in the free state. Somewhat similar experiments were made, in which seeds of wheat were sown in the sand, decomposing organic matter serving as manure. When the growth was allowed to continue long enough, the products contained more nitrogen than the seeds sown and the organic matter; in these cases it could not be said that the nitrogen not received by the plants as

* *Recherches Expérimentales sur la Végétation*, 1857.

ammonia had been taken up as nascent nitrogen evolved in the decomposition.

The conclusions from the collateral experiments were as follow :—

1. Organic matters in decomposition lose a part of their nitrogen as ammonia, and a part as nitrogen gas.

2. Vegetation does not interfere with the progress of this decomposition.

3. Plants cultivated in a manured soil, give more nitrogen in their produce than the manure yields as ammonia.

4. The excess of nitrogen in the produce has been absorbed as free gaseous nitrogen.

In regard to the explanation of the assimilation of free nitrogen by plants, M. Ville calls attention to the fact, that nascent hydrogen is said to give ammonia, and nascent oxygen nitric acid, with free nitrogen, and he asks,—Why should not the nitrogen in the juices of the plant combine with the nascent carbon and oxygen in the leaves? He further refers to the supposition of M. De Luca, that the nitrogen of the air combines with the nascent oxygen given off by the leaves of plants, and to the fact that the juice of some plants (mushrooms) has been observed to ozonize the oxygen of the air, and asks—Is it not probable, then, that the nitrogen dissolved in the juices will submit to the action of the ozonized oxygen with which it is mixed, when we bear in mind that the juices contain alkalies, and penetrate tissues the porosity of which exceeds that of spongy platinum?

Results and conclusions so astonishingly conflicting as those of M. Boussingault and M. G. Ville, have naturally incited others, either to investigate anew, or to seek in the conditions provided in their experiments, for some explanation of the discordance. A brief notice of the labours, or opinions, of these other experimenters or arbitrators, may be here subjoined.

In 1851, M. Mène* made three sets of experiments :—

1. Wheat and peas were, respectively, grown in powdered-glass, in free air, and watered with pure water. The wheat gained nitrogen equal to one-fourth of that in the seed sown, and the carbon, hydrogen, and oxygen, were doubled. The peas doubled the carbon, oxygen, and hydrogen, and trebled the nitrogen of the seed.

2. Lentils, peas, haricots, beans, wheat, rye, and oats, were

* Compt. rend. xxxii.

grown in a sterile matrix under a bell-glass, and supplied with an atmosphere of known composition, and with acetate of ammonia in the soil. The plants gained nitrogen, and the soil lost ammonia, but the nitrogen of the air was not perceptibly affected.

3. This series was similar to the second, but with the nitrogen of the air replaced by hydrogen. The plants flourished, and took up some of the acetate of ammonia.

M. Mène concluded that plants do not appropriate the free nitrogen of the air.

M. Roy, writing in 1854,* supposed that carbonate of ammonia was the chief source of nitrogen to vegetation; that Leguminous plants appropriated it from the atmosphere by their leaves; that Gramineous plants only took it up in solution by their spongioles; and that free nitrogen was not fixed by the leaves of plants, but when dissolved in water, and taken up by their roots, it could be assimilated. He concluded, that in M. Boussingault's experiments in limited air, there would be but little passage of solution of nitrogen by the roots, and evaporation of water from the leaves, and hence, not the necessary conditions for the assimilation of free nitrogen; but that with M. Ville's rapid current of air it would be otherwise.

In 1850, MM. Cloez and Gratiolet published the results of some experiments with water-plants, from which they concluded, that in the vegetation of such plants, nitrogen is given off from their nitrogenous constituents; that there must be restoration either from free or combined nitrogen; and that as their experiments showed ammonia-salts to be injurious to the plants, they probably take up free nitrogen dissolved in water.

In 1855, M. Cloez † published the results of some experiments on nitrification, in which he passed washed air for several months through twenty different combinations of porous, earthy, and alkaline matters. He found nitrates to be formed in notable quantity in calcined brick, or pumice, impregnated with alkaline or earthy carbonates, also in uncalcined brick similarly impregnated; but only traces in chalk, marl, a mixture of kaolin and precipitated carbonate of lime, &c. He considered, therefore, that the porosity of the pots and brick-fragments, the alkalinity of the ashes, the moisture, and the current of air, in M. Ville's experiments, provided the conditions for the formation of nitric acid. He asks, Can such formation take place in limited air?

* Compt. rend., xxxix.

† Compt. rend., xli.

M. De Luca * aspirated a large quantity of air in the neighbourhood of vegetation, through carded cotton, and then through sulphuric acid to wash it. The washed air then passed over potassium and through a dilute solution of pure potash, when nitrate was formed; but when air in the midst of habitations was operated upon in a similar way the formation of nitric acid was not observed. M. De Luca had found that the oxygen given off by plants in sun-light was in many cases ozonous, and supposed that by its means the nitrogen of the air may be converted into nitric acid, and that thus the nitrogen of the air may be rendered available for assimilation by plants, under the influence of vegetation itself.

In 1855, M. Harting† published some observations, and the results of some experiments, on the question of the assimilation of nitrogen by plants. He attributed a formation of ammonia from the decomposing debris of seeds, &c., and the free nitrogen of the air, in M. Ville's experiments; and he also supposed that nitric acid might be formed by the oxidation of the atmospheric nitrogen. The increase of nitrogen in M. Ville's plants, and of ammonia in the water of the enclosing apparatus, was taken as a proof of such formation of ammonia. He made two sets of experiments, in one of which the plants grew in a limited volume of air, and in the other in a current of air washed free from ammonia both being arranged with a view to avoid the formation of ammonia. However, the produced plants yielded no more dry matter than was contained in the seeds, and M. Harting considered, therefore, that the determination of the nitrogen was superfluous. The growth evidently stopped when the supplies of the seeds were exhausted. His general conclusions were as follow:—

1. Plants absorb salts of ammonia, and nitrates, by their roots.
2. The nitrogen of the air contributes to the formation of ammonia, and nitrates, in the soil.
3. It is not proved that nitrogen serves directly for the nutrition of plants.

In 1852 and 1853, M. H. M. Chlebowdarow made some experiments at Dorpat, under the direction of M. Petzholdt, who reported upon the results.‡ M. Petzholdt assumed that if plants can appropriate the free nitrogen of the air, they will not need

* Compt. rend., 1856.

† Compt. rend., xl. (1855).

‡ J. pr. Chem., lrv.

ammonia, and that if they take nitrogen from ammonia the supply of it will increase growth. The experiments were made upon barley. In 1852 an ignited yellow sand was used as soil. To one set of plants no ammonia was supplied, to a second carbonate of ammonia was provided in the soil, and to a third it was supplied in the air. The crops with a supply of ammonia gave three times as much produce, and much more nitrogen, than those without it. In 1853, six sets of experiments with barley were made, the soils consisting of an artificial mixture of clay, sand, and felspar decomposed by heating with lime. To one set of three pots, no manure was added; to the second, a small quantity of bone-ash, decomposed by sulphuric acid; and to the third, a larger quantity of the same phosphatic mixture. The three other sets were arranged like the above, and had, in addition, ammonia supplied to the atmosphere in which the plants grew; the experiments, without ammonia, being made in free air, and those with it in an enclosing apparatus. The nitrogen of the crops was very much increased by the aid of the phosphatic manure, and still further by the addition of the ammonia to the atmosphere of the plants. M. Petzholdt considered it difficult to account for the fact of M. Boussingault getting little or no increase of nitrogen in free air, which must have supplied some ammonia, even though rain and dew were excluded.

The results or conclusions of these several arbitrators are seen to be nearly as conflicting as those of M. Boussingault and M. G. Ville themselves, nor are we able to discover, either in the differences of plan, as described by M. Boussingault and M. G. Ville themselves, or in the results and explanations of other experimenters, a satisfactory solution of the difference of result arrived at.

From the chemical characters of nitrogen itself, and from what is known of the chemistry of vegetation in other respects, it would be concluded that plants would not assimilate nitrogen offered to them in the free state. On the other hand, the total amount of actually existing combined nitrogen is very large, and there is an amount of nitrogen periodically available for the vegetation of a given area of land, the source of a considerable proportion of which is, to say the least, not yet quantitatively explained; and, upon the decision finally come to in regard to the question whether or not the assimilation of free nitrogen

by plants, may account for all, or a part of the otherwise unexplained amount, must materially depend the degree of importance to be attached to the further investigation of the other actual or possible sources of nitrogen to plants which have been briefly noticed. It seemed desirable, therefore, that the subject should be submitted to further enquiry, and we now proceed to give a condensed account of our own experimental evidence on the point.

IV.—*Experimental results obtained at Rothamsted in 1857, 1858, and 1859, on the question of the Assimilation of Free Nitrogen by Plants, and some Allied Points.*

In the treatment of this part of our subject, it is proposed to consider—

1. The conditions required, and plan adopted, in the direct experiments on the question of the assimilation of free nitrogen by plants: embracing those which relate to the requirements and preparation of the soil or matrix, and of the nutriment to be supplied to the plants, the selection of plants and seeds, the atmosphere to be provided, the description of apparatus adopted, and the mode of using it (which should be so arranged as to include all that is necessary for the healthy and vigorous growth of the plants, excepting, in some instances, a full supply of combined nitrogen), and lastly, the question of the analytical methods adopted, and of their competency to serve the purposes of the enquiry.

2. A number of collateral questions having a bearing upon the points at issue: including those of the possible influence of ozone on the supply of combined nitrogen to growing plants, of the action of ozonised air on decomposing organic matter, and porous and alkaline substances, of the evolution of free nitrogen in the decomposition of nitrogenous organic matter, and of the mutual relations of gaseous nitrogen and the nascent hydrogen evolved during the decomposition of organic matter.

3. The results of the direct experiments themselves on the question of the assimilation of free nitrogen by plants.

Conditions required, and plan adopted, in Experiments on the question of the Assimilation of Free Nitrogen by Plants.

So complicated is the constitution of ordinary soils, and so intimately are the nitrogenous compounds existing within them associated with other matters, that it is impossible either to estimate their

nitrogen with sufficient accuracy for our present purpose, or to extract it from the soil without entirely destroying the other conditions of vegetable growth ; nor could a natural soil be so imitated by artificial means, as to include all its conditions excepting a supply of combined nitrogen. There exists, however, abundant evidence to show that many of the complicated conditions of an ordinary soil may be entirely dispensed with, so as to bring the examination within our means of investigation, and yet, to retain all the conditions of healthy growth. The experiments of others to which attention has been directed, are sufficiently conclusive on this point, and the results now to be recorded bear similar testimony.

In the experiments of the first year, 1857, two kinds of soil, or matrix, were used ; one prepared from an ordinary soil, and the other from volcanic pumice. The latter substance was employed with a view to eliminate certain supposed sources of error which the prepared soil might introduce ; but results, to which reference will be made, showed the precaution to be unnecessary, and, in 1858, only prepared soil was used.

A somewhat clayey soil was selected ; and, after the large stones had been removed, and the clayey lumps powdered, it was ignited in a large cast-iron muffle, through which a constant current of air passed, until, on removing a portion, and cooling it, it exhibited the red colour due to peroxide of iron, and showed no traces of coal matter. The mass was then thrown into a large volume of distilled water, which was rendered strongly alkaline by the caustic lime present. After stirring, and being allowed to settle, the fluid was decanted, then fresh water added, and the operation repeated frequently during eight or ten days, until all the soluble matter was removed. The residue was then dried and retained for final ignition before use.

The ferruginous and aluminous character of this soil-matrix pointed to the possibility of its acting as a porous body in promoting the formation of nitrogenous compounds, or absorbing and retaining the ammonia supplied to the plants, or that which might be formed from the nitrogenous matter of the seed. In order to ascertain whether any formation of nitrogenous compounds in the manner here supposed occurred, a pot of soil, prepared as for an experiment with a plant, was submitted to the same conditions of air, temperature, moisture, &c., as the pots containing the experimental plants, but no accumulation of combined nitrogen took place.

When volcanic pumice was used, it was powdered until the greater portion was quite fine, and the largest pieces were about the size of peas. The powder was then subjected to long washing in the same manner as the ignited soil, and lastly, dried ready for final ignition before being used.

The necessary mineral constituents were in most cases supplied in the form of the ash of the plant of the description to be grown, or, if this were not practicable, of that of some closely allied kind. In some instances the ash was obtained by burning a quantity of the entire plant when in seed; in others, the seed and the rest of the plant were burnt separately, and a mixture of the two ashes made in the proper proportions. Strongly alkaline ashes (of Leguminous plants) were sometimes saturated with sulphuric acid, and the mixture ignited. The ashes were prepared in large shallow platinum dishes, heated in a current of air in a cast-iron muffle, and the burning was continued until all coaly matter disappeared. Examination failed to detect combined nitrogen in any of the ashes so prepared. A consideration of the chemical constitution of soils suggested a proportion of 0.8 to 1.0 per cent. of ash, and this was the quantity added to the matrices in 1857, but in 1858 only about half as much was employed.

In some cases weak solutions containing phosphoric acid or sulphuric acid were used as well as ash.

The strength of a dilute solution of phosphoric acid was determined by means of a titrated alkali-solution, and it was then neutralised by carbonate of soda. Each pipette measure of the solution given to the plants supplied about 0.01 gramme phosphate of soda. It was only employed in the experiments of 1858.

The sulphuric acid solution, which was also only employed in 1858, was prepared by determining the strength of some very dilute pure acid, in the same manner as that of the phosphoric acid. It was then so far reduced that the pipette measure by which it was applied to the plants contained exactly as much sulphuric acid as the pipette of sulphate of ammonia solution then in use, which corresponded to 0.004 gramme nitrogen.

When ammonia was supplied to the plants, it was given in the form of a weak solution of the sulphate, which was prepared as follows:—Ordinary ammonia-water was distilled from a flask and the vapour condensed in pure distilled water. The strength of the solution was determined by the volumetric method against that of dilute sulphuric acid of known strength, the preparation

of which is described further on. A given volume of the ammonia-liquid was then neutralised by pure dilute sulphuric acid, of which the measure added was determined, and the strength of the sulphate-solution calculated accordingly. It was intended that each cubic centimetre should contain about one-tenth of a milligramme of combined nitrogen, and generally 4 to 6 milligrammes were supplied at once.

The value of each of the above solutions was determined by analysis, to insure that its composition was such as was supposed.

The plants were watered with distilled water, in the preparation of which the first two-fifths of the distillate from ordinary water were allowed to escape, and the next two-fifths were collected for further treatment. This water retained traces of ammonia. It was mixed with a little phosphoric acid free from nitric acid, and then re-distilled from a copper vessel, to which a glass condenser was attached.

All parts of the apparatus, the presence of ammonia in which could possibly affect the result, were, after thorough washing both with ordinary and common distilled water, finally rinsed with this pure double-distilled water just before being used.

In the experiments of 1857, common flower-pots were used, and small common white-glazed plates were employed as pans. For the experiments of 1858, observation suggested the kind of pot and pan represented in figs. 1, 2, and 3, plate I. The pot was made of the same material as ordinary flower-pots, but as light as possible, and it was somewhat less baked. The height and diameter at the top were each five inches, and the diameter at the bottom was four inches. The bottom, and the sides to a distance of one inch from the bottom, were perforated with numerous holes of nearly one-fourth of an inch diameter, as shown in figs. 1 and 2. The pan, represented in fig. 3 with the pot placed in it, is made of hard baked and well-glazed stoneware. It is 1.5 inch deep and 5.2 inches in diameter at the bottom. At the top it is curved inwards (A, B, fig. 3), so as to adapt its upper rim to the sides of the pot. These arrangements reduced the surface for evaporation from a given volume of soil, and facilitated the exit of the roots, and the access of air. The pan affords room for an abundance of water, in which the roots develop luxuriantly, and are protected from the direct action of sun-light. Thus, a minimum of evaporation from other sources, and a drier atmosphere, being maintained, evaporation through the plant itself is favoured; and hence

the conditions are provided for a constant supply to the plant of all the mineral and gaseous substances in solution in the fluid of the soil and pan.

In preparation for an experiment, the soil, the ash, and the pot, were simultaneously heated to redness, and the soil and ash, whilst red-hot, were mixed together in the red-hot pot, which was placed upon a red-hot brick, over sulphuric acid, the whole being then covered with a large glass shade, and left to cool. In 1857, from $2\frac{1}{2}$ to 3lbs. of ignited soil were put into each pot; but, in 1858, the lower part of the pot was first filled, to the depth of about one inch, with very coarsely broken up red-hot flint. The greater portion of the ash was mixed with the lower layers of soil, but some was distributed through the whole of it. After cooling sufficiently, the shade was removed, and about 500 cub. centims. of pure distilled water were added to the soil of each pot; and, after ten to twenty hours more, the seeds were put in.

In all the experiments recorded, the plants were grown directly from seeds, sown in soils prepared as above described. A quantity of seed of very good quality being procured, the largest and smallest, or any looking unhealthy, were picked out. Given numbers of the remainder were then weighed, and the average weight per seed was calculated. A few, weighing as nearly as possible the mean weight, were then selected for planting, and a number of others, of equal weight and character, were reserved for the determination of their nitrogen, as a means of estimating the quantity supplied in the seed sown.

The quantity of ammonia in the atmosphere is so small, that, had it been intended to grow the experimental plants in limited volumes without change, the amount of combined nitrogen available to the plants by its means might have been entirely disregarded; but as, for various reasons, it was decided that the plants should grow in an enclosing apparatus through which a current of air passed, it was freed from ammonia, and solids mechanically suspended, by washing in the manner presently to be described, before being admitted into the apparatus.

Owing to the small proportion of carbonic acid in the atmosphere, and to the fact that a part of it would be absorbed in the washing process just referred to, it was necessary to give a supply of it to the plants artificially. This was obtained by the action of chlorhydric acid upon fragments of marble, and the arrangements for its supply will be described presently, with the rest of the

apparatus. Boussingault found* that the air surrounding a plant might, consistently with healthy growth, contain 8 per cent. of carbonic acid, whilst the normal atmosphere, in which vegetation flourishes, contains only 0.04 per cent. Calculation showed that a minimum of 0.2 per cent. of carbonic acid in the air of the enclosing apparatus would supply very much more than was required by the plants: and from the observations of Boussingault it was concluded that 4 per cent. might be adopted as the maximum. Further, our own experiments on the nature of the gas in plants show (as will be seen further on) that the changes in the proportion of carbonic acid in the air of the cells and intercellular passages, and in the fluids of the stem, are much greater and more rapid than those which could take place in the atmosphere of our experimental plants. Moreover, plants derive much of their carbonic acid from aqueous solution absorbed by the roots, and most probably the remainder is taken up by the fluids of the plant before influencing its growth. These absorptions can take place but slowly, so that rapid variations in the proportion of carbonic acid in the atmosphere of the plant, will be accompanied by much less variation within it. It was considered probable, therefore, that there would be no danger in so supplying carbonic acid to the atmosphere of the plants, as to reach the proposed maximum proportion in a short time, and then, by the passage of the air, bring it gradually down to the minimum.

In practice, a little more chlorhydric acid was added at one time to the marble than was necessary to provide 4 per cent. of carbonic acid in the atmosphere of the plants, and the passage of the air was commenced simultaneously. Repeated analyses of the air in the enclosing apparatus showed that the limits of 4 per cent. as the maximum, and 0.2 per cent. as the minimum, were not passed when operating in this way.

The description of apparatus used for each separate experiment in 1858 (and subsequently), to enclose the plants, and to supply them with air, water, carbonic acid, &c., is represented in fig. 1, plate II.; and that used in 1857 only differed in some few points, to the chief of which reference will be made.

A, represents a large stoneware Woulfe's bottle, 18 inches in diameter, and 24 inches high. *a* represents the cross section of a leaden pipe $1\frac{1}{2}$ inch diameter (which is connected with a reservoir

* *Mémoires de Chimie Agricole et de Physiologie*, 1854, p. 441.

of water not shown), and which passes over a series of vessels A, at right angles to the plan of the figure, and is connected with each by the tube *ab*, in which is fixed a stop-cock to open and shut the connexion between the water-supply tube *a* and the vessel A. *cde* is a leaden exit-tube for air, enlarged at the point *c*, and downwards, until it opens into the vessel A, thus allowing the half-inch safety-tube, *qrs*, to pass through it and down to the bottom of the vessel A, as indicated by the dotted line.

The bottles B and C (which with T, E, and O, are each of about 30 ounces capacity), contain sulphuric acid of sp. gr. 1.85, to a depth of $2\frac{1}{4}$ inches. The tube DD is about 3 feet long and 1 inch diameter, filled with fragments of pumice saturated with sulphuric acid, in which, at *ff* are indentations to prevent the sulphuric acid from draining against the corks. The bottle E contains a saturated solution of ignited carbonate of soda, and its interior is connected with that of the glass shade F, by means of the bent, and caoutchouc-jointed glass tubes *gh*.

The shade F is about 9 inches in diameter and 40 inches in height, but in some experiments, shades 16 inches in diameter and 28 in height were used. *ik* (better indicated in fig. 2, plate II) is the exit tube for the air, and is connected, externally to the shade, with an eight-bulb apparatus, M, containing sulphuric acid. *uv*, also better indicated in fig. 2, is for the supply of water, or solutions, to the soil; and *no* is for the escape of condensed water into the bottle O, to the bottom of which passes another glass tube *t*, by means of which the condensed water which collects in it is withdrawn.

ww is a lute-vessel of hard baked and well glazed stoneware, and is, in fact, simply a shallow dish with double concentric sides, the space between which forms a groove for the reception of the shade and of the luting material, which was mercury, and for the passage of the tubes. Fig. 4, plate I, is a plan of the stoneware lute-vessel, which shows the groove widened and deepened at four equidistant points for the passage of tubes underneath the shade, and also the hole *n* for the escape of the condensed water. Fig. 5 is a vertical section of the lute-vessel from A to B of fig. 4, through two of the widened and deepened portions of the groove, and through the orifice *n*; and fig. 6 is a vertical section from C to D of fig. 4.

The bottle T contains fragments of marble, from which carbonic acid is evolved by the addition of measured quantities of chlorhydric acid, supplied by means of the tube *y*.

In 1857, blocks of slate 12 inches square and $3\frac{1}{4}$ inches thick, with a circular groove, $\frac{1}{2}$ an inch wide and 2 inches deep, adapted to the diameter of the shades, but widened and deepened for the passage of the tubes, were used instead of the stoneware lutes above described; and the condensed water was withdrawn by means of a bent tube passing from the outside beneath the shade, and extending to the surface of the mercury in the groove within the shade.

On opening the stop-cock below *a*, (fig. 1, plate II) water flows into the vessel A, from the reservoir with which the tube *a* is in connection. As the pressure increases, the water rises in the safety-tube *q r s*, above the level in A, and air escapes by the tube *c d e*, forces its way through the sulphuric acid in the bottles B and C, through the tube D D, containing pumice saturated with sulphuric acid, then through the solution of carbonate of soda in E, enters the shade F by the tubes *g h*, and passes out through the tube *i k*, and the bulb apparatus M, containing sulphuric acid. Calculation showed that the minimum pressure required to force the air through the apparatus was equal to that of a column of mercury 1.037 inch in height. The difference between the height of the water in A and in the safety tube *q r s*, must be equal to this amount multiplied by the specific gravity of mercury; and the height from the top of the vessel A to *r* being about twelve inches, the whole of the air passed out of A before the water ascended to *r*, and flowed out of *q*; whilst the great height of *d* prevented the water from passing over into the bottle B; an accident which unfortunately happened on a few occasions in 1857, when the air and safety-tubes were somewhat differently arranged.

When the vessel A was full of water, it was let off by a cork hole at the bottom, air being at the same time admitted by the tube *x* at the top.

The minimum pressure upon the inside of the glass shade F would be $\frac{1.0 \times 1.85}{13.6} = 0.136$ inch, 1.0 being the difference between the levels of the sulphuric acid in the bulb-apparatus M; but owing to friction, &c., the maximum pressure might be raised to double this calculated minimum.

All the Woulfe's bottles were made as air-tight as possible, by means of very good corks, which, in the cases of E and O, were covered with a cement composed of 8 parts gutta percha, 12

parts common rosin, and 1 part Venice turpentine, well melted together. The glass tube *n o* was also fixed into the lute-vessel at *n* with this cement. At first, tubes of unvulcanised, but afterwards of vulcanised, caoutchouc were used for the various joints indicated. The ends of the tubes *t* and *u* were fitted with caoutchouc tubing, into which pieces of solid glass rod were fitted as stoppers.

In 1857, twelve such sets of apparatus, and in 1858 a larger number, were employed. The whole were arranged side by side, on stands of brickwork, in the open air, and were protected from rain, or the too powerful rays of the sun, by a canvas awning which could be drawn over them, or withdrawn, at pleasure. In 1858, two glass cages, such as were used by M. G. Ville, and which he kindly sent over to us, were also employed.

The volume of washed air passed through the apparatus daily, was, in the earlier experiments, that of the vessel A, equal to about two and a half times that of the shade F, but in the latter ones generally twice as much, or more.

The apparatus above described has the following advantages:—

1. When it is once enclosed, and the mercury poured into the groove, the plant is entirely excluded from all external sources of combined nitrogen; and, in case of its being necessary to open the vessel, this can be done with great facility.

2. By means of the tube *n o*, and the bottle O, the water which condenses within the shade is quickly removed from the atmosphere of the plant. The pan in which the pot stands, with its inward-turned rim, allows of a store of water being kept beneath the plant, which, at the same time, is protected from free evaporation. Water is very easily supplied by the tube *u v*, and the bottle O holds as much as can be condensed during several days; its contents are easily removed by means of the tube *t*, and returned, if required, by the tube *u v*.

3. A simple glass shade is more easily cleaned before commencing the experiment, and is less likely to retain combined nitrogen at its termination, than a complicated metallic framework with panes of glass cemented into it; whilst the presence of oxidisable metallic surfaces is avoided.

4. The only organic matter within the shade is the thin coating of cement by which the tube *n o* is fixed into the hole *n* at the bottom of the lute; and analysis showed, that even if the whole of the cement in contact with the condensed water became decomposed, it

could only yield a fraction of a milligramme of nitrogen, whilst experiment proved that it did not suffer sensible decomposition when exposed in the open air during a whole year.

5. During the passage of the air, the excess of pressure is upon the inside of the enclosing vessel, instead of, as in the experiments of others, upon the outside, and hence, any leakage would be from within outwards, instead of from without inwards, by which extraneous combined nitrogen might be introduced; and when the air is not passing, any pressure in the opposite direction, due to changes of temperature and barometric condition, can never exceed that required to drive air inwards through the sulphuric acid in the bulb-apparatus M.

6. The part of the apparatus which is most liable to leak, and would be the most damaged by pressure, is subjected to the minimum amount of it, the only pressure exerted upon the glass shade being the amount requisite to force the air through the bulb-apparatus M.

Lastly, in reference to the arrangements for experiment, it may be observed, that the proportions of nitrogen and oxygen in the air can be only very immaterially affected by absorption under the influence of the slightly increased pressure in the vessel A; that provided the whole of the carbonic acid of the air were absorbed by the water, this would be of no consequence, arrangements being made for its artificial supply; and, that although the air may take up a considerable amount of water in the vessel A, it must lose most or all of it in passing through the sulphuric acid in the bottles B and C, and over the pumice saturated with sulphuric acid in D D, and the re-dried air will pass too rapidly through the carbonate of soda solution in E for re-saturation, whilst, as the air will be cooler before it enters the shade than within it, it will not be then so near its point of saturation.

The conditions of atmosphere provided were proved to be adapted for healthy growth, by growing wheat, barley and beans, under the adopted conditions, but in a good garden soil, when luxuriant vegetation was the result. (See fig. 13, plate III.)

The conditions of the artificial soils were shown to be suitable for the purposes of the experiments by the fact, that plants grown in such soils, and in the artificial conditions of atmosphere, developed luxuriantly if only manured with substances supplying combined nitrogen. (See figs. 7-12, plate III.)

Taking up the Plants, Preparation for Analysis, Methods of Analysis, &c.

At the termination of growth, the glass shade was washed outside, quicksilver was poured into the groove, to displace from it the condensed water not removable by the arrangement of 1857, or collected in the bottle O of 1858, as the case might be, and the shade was then removed. The previously covered portions of the slate or stone-ware lute were then washed with pure distilled water, and the washings added to the condensed or drain-water. In the experiments of 1858 this fluid was analysed separately, but in those of 1857, it was mixed and dried down with the soil.

The pot with its contents, was removed to a clean table covered with white paper, the plants measured in all their parts, and then cut off at the surface of the soil; the roots were removed, slightly washed from soil and their character noted. The plants were then put into a small wide-mouthed bottle, generally stem and root together, but sometimes they were put into separate bottles. In the experiments of 1857 the contents of the bottles were dried in a water-bath, with a current of air, previously washed with sulphuric acid, passing through the bottle and thence through a solution of a known quantity of pure oxalic acid; but as no appreciable amount of ammonia was thus accumulated, in 1858 a little oxalic acid (in solution) was added to the vegetable matter, and the whole dried in the water-bath without the above precaution.

When dry, the vegetable matter was cut small by means of a pair of clean long scissors reaching to the bottom of the bottle, and it was afterwards still further reduced by grinding up in the mortar when mixed with soda-lime for analysis. When duplicate analyses were made, the matter was carefully divided, so as to ensure equal proportions of stem, fine leafy matter, &c., in each half; so that, if both analyses were successful, the results were mutually confirmatory, or if one portion were lost, the other represented a proportional amount of the whole.

The soil was removed from the pot to a porcelain dish, and a sufficient amount of a solution of oxalic acid added to keep it acid. The mixture was then heated on a sand-bath, stirring constantly, until most of the water was expelled, more fully dried in the water-bath, and then preserved in well-corked bottles for

analysis. The pots were pounded up; those of 1857 being preserved and analysed separately, and those of 1858 mixed with the soil before it was dried with oxalic acid. The pieces of flint at the bottom of the pot were also pounded and mixed with the soil.

For analysis, 150 to 200 grammes of the soil, pot, or mixture, were mixed with about half the volume of soda-lime, the whole put into a large combustion-tube, some soda-lime put in advance of the mixture, and then asbestos, as usual. The combustions were made in charcoal furnaces, and the ammonia collected in titrated sulphuric acid (see p. 43). When very small quantities of nitrogen were evolved, the ammonia from two or three tubes of substance was sometimes collected in the same quantity of acid, so as to diminish the error of titration. It was found, however, to be better to use very small quantities of acid, and to estimate the product of each combustion separately; for, by the former method, if any accident occurred in the second or third combustion, it involved the loss of the determination of the products previously collected.

Preparation of the Titrated Solutions.—A weighed quantity of pure, dry, carbonate of soda was dissolved in water, and water added to a given volume. As a preliminary step, the strength of some dilute sulphuric acid was tested against a given volume of the carbonate of soda solution; and from the data obtained, by further dilution a large quantity of acid was made of about the strength desired. The exact value of this acid was then ascertained. To accomplish this, a given volume of the carbonate of soda solution was put into a beaker, a little litmus added, and the mixture heated over a spirit lamp. The acid was then allowed to flow from a burette until a wine-red colour (indicating the presence of bicarbonate with carbonic acid in solution) was produced. On boiling, the blue colour is restored; acid is added until red; the boiling is repeated until the blue returns; acid again added, and so on, until the solution remains red on the addition of the last drop. The point at which the permanent change takes place in the first trial being known, the experiment is easily repeated so as to ensure great accuracy.

Thus, 50 septems of carbonate of soda solution, of which 1,000 septems contained 6.652 grammes of the salt, required, for neutralization, in six different trials—58.3, 58.2, 58.3, 58.3, 58.2, 58.2; mean 58.25 septems. Hence—

$$\frac{6.652}{1000} \times \frac{50}{58.25} \times \frac{N}{\text{NaO.CO}_2} = \frac{6.652}{1000} \times \frac{50}{58.25} \times \frac{14}{52.98} = 0.001508 \text{ gramme N.}$$

The mean of six experiments with a solution of carbonate of soda of another strength gave, in the same way, 0.0015008 gramme nitrogen. The mean, or 0.001504 gramme, was therefore adopted as the amount of nitrogen corresponding to 1 septem of the titrated acid.

As the alkali, to test against this standard acid, a solution of sugar-lime was first employed, but being found liable to constant change, due doubtless to fermentation, a solution of caustic soda was had recourse to. The burette was of small enough diameter to allow of one-tenth of a septem being read off on it, and the alkali-solution was so dilute that it required about 3 septems of it to neutralise 1 septem of the acid. Hence, 1 septem of the alkali-solution corresponded to only about half a milligramme of nitrogen, and the probable error of reading would therefore be only about one-twentieth of a milligramme—an amount much less than would be admissible as error of analysis. In the case of the sugar-lime solution it was found necessary to test its strength against that of the acid every day that it was employed. But the soda-solution, if properly prepared, and well preserved, remained for months unchanged.

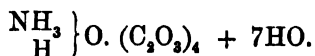
Amount and measurement of the Titrated Acid used in Nitrogen Determinations.—It was desirable that at least 3 times as much acid should be used as would be neutralised by the ammonia formed. The acid being more concentrated than the alkali, it required a more exact method of measurement; and pipettes, of which the diameter at the point of reading off was comparatively small, were therefore employed; in the construction of which, care was taken to maintain the same relation of the diameter of the neck at the point of reading to the entire volume in instruments of different sizes—a condition seldom observed by makers of pipettes. When the quantity of nitrogen involved in an analysis was very small (as is the case of the soils and pots in the experiments without nitrogenous manure), only about 6 septems of the titrated acid, measured in a small pipette with a very narrow neck were used, the exact volume of which was of no consequence, it being only essential to ascertain its exact value expressed in septems of the titrated alkali-solution. When the amount of nitrogen involved was larger, as, for example, when

grains were to be analysed, sufficient accuracy was attained when the substance experimented upon contained 5 to 8 milligrammes, or more, of nitrogen.

Combustion-tubes, Bulbs, &c.—The tubes used in the determinations of nitrogen in the soils, pots, &c., were about 3 feet long and about 1 inch in diameter. The bulb-apparatus was capable of holding two and a half to three times as much fluid as that usually employed; but the central and lowest bulb, and particularly its tubular connexions with the other bulbs, were very small, so that a small quantity of liquid could close the passage. This arrangement was necessary, owing to the small quantity of acid frequently used, and the large amount of water driven off in the combustion from the large quantities of soil and soda-lime. For the combustion of the experimentally grown plants, smaller tubes were employed; and for the seeds, &c., ordinary combustion-tubing was used.

Soda-lime.—Before use, the soda-lime was ignited with 2 per cent. of pure sugar, in order to ensure its freedom from ammonia yielding matter. It was then slaked with pure distilled water, dried, and kept in well-corked bottles.

Accuracy of the Method for the Determination of Nitrogen by Combustion with Soda-lime, &c.—In order to ascertain the accuracy of the method, some experiments were made upon the determination of small and known quantities of nitrogen, mixed with large quantities of soil previously freed from combined nitrogen as in the preparation of the soils for the plant-experiments. The nitrogenous substance taken was the powdered crystals of purified quadroxalate of ammonia—



The results were—

Experiment 1.—50 grammes of prepared soil, mixed with quadroxalate, containing by calculation 0·0024 gramme nitrogen, gave on burning with soda-lime, and determining as above, 0·0027 gramme.

Experiment 2.—100 grammes of soil, mixed with quadroxalate, equal by calculation to 0·0035 gramme nitrogen, gave on combustion 0·0037 gramme.

The error of analysis was, therefore, three-tenths of a milligramme of nitrogen with the 50 grammes, and two-tenths with

the 100 grammes of soil. These results were obtained at the commencement of the inquiry, with comparatively large quantities of the titrated acid, and before experience had suggested the precautions to be adopted to reduce the errors of determination to the minimum. They may hence be taken as examples of the maximum errors of analysis, but they are less than would affect the bearing of the results in the investigation on the question of assimilation.

Qualitative Examination for Nitric Acid.—The indigo test, as recently refined by Boussingault,* and the protosulphate-of-iron test, were both employed. When nitric acid was sought for and not found, the negative result was, if practicable, always controlled by the addition to some of the substance under examination of a quantity of nitric acid (in the form of nitrate) less than could affect any conclusions to be drawn from the fact of its presence or absence in the substance in question; and, in all such cases, the re-examination showed the presence of nitric acid.

The method of Boussingault was much more delicate than the protosulphate-of-iron test; but, on the other hand, the latter was much less liable to give deceptive indications, dependent on other circumstances than the presence of nitric acid. In using the protosulphate test, the aqueous extract of the substance under examination (after destroying any organic matter by boiling with permanganate of potash, &c.), was evaporated to a small volume with excess of fixed alkali, then transferred to a test-tube, and further evaporated till only a few drops remained. A considerable excess of concentrated sulphuric acid was then added, and on the surface of the liquid, a concentrated solution of protosulphate-of-iron was carefully poured, without agitation, by means of a small pipette with a mouth of almost capillary fineness. The characteristic tinge indicated the presence of nitric acid.

Conditions of Experiment requiring Collateral Investigation.

Under this head it is proposed to consider:—1. The possible influence of ozone in promoting the formation of nitrogenous compounds from free nitrogen, either within or in connexion with the

* Ann. Ch. Phys., vol. xlviii. (1856), p. 153 et seq.

plant, or within the soil, either directly, or in connexion with the organic matter of the plant. 2. Whether or not there be an evolution of free nitrogen in the decomposition of nitrogenous organic matter. 3. Whether, under the circumstances of the experiments, there would be likely to be a formation of nitrogenous compounds, by the mutual action of nascent hydrogen (evolved by decomposing organic matter) and free nitrogen.

With regard to the first point, ozone may be supposed to occur within the cells and intercellular passages of the plant, either in the gaseous state or in solution, or it may be simply around the plant without existing in its structures. It may be a product of the action of the sun's rays, by virtue of which carbonic acid is decomposed and oxygen evolved, or it may result from other actions to which reference will presently be made.

To ascertain experimentally, if possible, whether ozone were present within the cells or intercellular passages, the gases obtained by exhausting plants placed in water freed from air by boiling, were examined, but no ozone was detected. Other experiments were also made, in which about an ounce respectively of green wheat, barley, oats, beans, and clover, were placed in 500 cub. cent. of carbonic acid water, and the whole subjected to sunlight, but though from 100-200 cub. cent. of gas were obtained, which contained sufficient oxygen to inflame a glowing taper, test-paper placed in it did not indicate a trace of ozone. Granting, however, that ozone may, under certain circumstances, be a product of the decomposition of carbonic acid within the plant, it is still a question whether such conditions would be favourable to its oxidating free nitrogen; an action which will obviously be dependent on the intensity of the reducing power of other substances present. The investigations of Schönbein and others appear to show that, under certain circumstances, nitric acid may be formed by the mutual action of ozone and free nitrogen; but the question is, whether these circumstances are presented in the cells and intercellular passages of growing plants, a point which we have sought to study by the examination of the gases they contain under various circumstances.

Plants, or parts of plants, were put into a flask filled with water which had been freed from air by boiling; a cork, through which a bent glass tube was passed, was then pressed into the flask, filling the tube with the displaced water. The flask was then

placed over a lamp, the water boiled, and the expelled water and gas collected over mercury, the boiling being continued until the vapour produced expelled most of the water collected over the mercury. The gas so obtained, in numerous experiments, consisted entirely of nitrogen and carbonic acid, without any oxygen; from which it is obvious that the reducing power of the carbon compounds in the vegetable cells, was sufficient, under the circumstances, to consume all the oxygen (or ozone) that might be present. But the high temperature at which the experiment was conducted must have tended very much to increase this action.

In all subsequent experiments a different plan of operation was adopted. The plants were put into a tall glass vessel, 14 inches high, and 1.75 inch in diameter (fig. 7, plate I), the mouth of which was fitted with a long cork, previously well-boiled in bees'-wax, through which two glass tubes, *a* and *b*, are inserted. The vessel being filled with water previously well-boiled and cooled without access of air, the plant is put in and well-shaken to remove adherent air-bubbles. The cork is then forced in, taking care that both the tubes become filled with water, and that no air remain in the vessel. As a further security for tightness, a piece of thick caoutchouc tubing may be drawn over the neck of the vessel, projecting upwards a little above the cork, and the cup thus formed, partly filled with melted wax, forming a layer over the cork and its joints. A funnel is then attached to the tube *b*, by means of a caoutchouc tube which can be closed by a strong pinch-cock. Water being admitted through the funnel into the tube *b*, the tube *a* becomes filled, and it is then brought into connexion, by means of a glass tube and caoutchouc joint fitted with a pinch-cock, with a vessel filled with quicksilver. The connexion being opened, the quicksilver is allowed to flow from the vessel by means of a long tube, of more than barometric length, fitted into the lower part of it, thus forming a Torricellian vacuum in the mercury vessel. The gas from the plant passes over into the vacuum, and by a simple arrangement is collected in an eudiometer tube for examination.

The following table (VIII) shows the amount and composition of the gas obtained in the manner above described, from different plants, *in the shade* :—

TABLE VIII.

Date.	Description.	Total gas col- lected; cub. cents.	Per cent.			
			Nitrogen.	Oxygen.	Carbonic acid.	Oxygen and carbonic acid.
Wheat; 1858.						
June 16.	Whole plant	57.0	77.72	2.28	20.00	22.28
June 17.	Whole plant	55.3	77.94	5.06	17.00	22.06
June 16.	Whole plant	57.0	78.60	1.75	19.65	21.40
June 16.	Whole plant	55.7	77.38	3.23	19.39	22.62
June 16.	Whole plant	65.7	82.50	0.30	17.20	17.50
Barley; 1857.						
June 24.	Whole plant	8.6	85.12	3.93	10.95	14.88
June 24.	Whole plant	20.9	81.48	1.97	16.55	18.52
Beans; 1858.						
June 17.	{ Whole plants coming into flower }	54.3	79.74	5.16	15.10	20.26
June 17.	{ Whole plants coming into flower }	41.5	86.74	4.10	9.16	13.26
June 17.	{ Whole plants coming into flower }	52.5	80.38	4.38	15.24	19.62
June 17.	{ Whole plants coming into flower }	50.4	84.33	4.36	11.31	15.67
Clover; 1857.						
Aug. 10.	Heads	47.7	85.61	6.00	8.39	14.39
Aug. 10.	Stems and leaves	59.8	83.23	2.33	14.44	16.77
Aug. 11.	Heads	91.0	87.15	1.89	10.96	12.85
Aug. 11.	Stems and leaves	42.3	78.32	1.31	20.37	21.68

These results show that the reducing power of certain of the carbon compounds of the plant was sufficient to convert nearly the whole of the oxygen (or ozone) present, into carbonic acid, when in the shade.

Over 100 exhaustions were made, precisely as in the case of the last experiments, with the exception that the plants were exposed, during the whole process, to the direct rays of the sun. Table IX exhibits a few of the results obtained:—

TABLE IX.

Date.	How manured, &c.	Total gas col- lected; cub. cents.	Per cent.			
			Nitrogen.	Oxygen.	Carbonic acid.	Oxygen and carbonic acid.
Wheat (whole plants); 1858.						
June 22.	Unmanured	44.4	73.65	21.17	5.18	26.35
June 23.	Unmanured	34.8	77.01	21.26	1.73	22.99
June 30.	Unmanured	44.1	72.79	20.86	6.35	27.21
June 22.	{ Mineral and ammo- niacal manure }	54.5	73.76	21.29	4.95	26.24
June 23.	{ Mineral and ammo- niacal manure }	42.1	78.15	15.44	6.41	21.85
June 25.	{ Mineral and ammo- niacal manure }	37.2	78.76	19.09	2.15	21.24
Grass (whole plants; second crop); 1857.						
Aug. 15.	{ Mineral and ammo- niacal manure }	39.0	82.10	16.19	1.71	17.90
Aug. 15.	{ Mineral and ammo- niacal manure }	47.8	77.03	15.35	7.57	22.92
Aug. 15.	{ Mineral and ammo- niacal manure }	41.6	76.56	21.46	1.98	23.44
Aug. 17.	{ Mineral and ammo- niacal manure }	39.9	75.07	23.39	1.54	24.93
Aug. 18.	{ Mineral and ammo- niacal manure }	36.8	79.88	15.19	4.93	20.12
Aug. 18.	{ Mineral and ammo- niacal manure }	42.3	80.23	15.97	3.80	19.77
Beans; 1858.						
July 12.	{ Mineral manure; al- most podding }	44.3	71.11	18.28	10.61	28.89
July 12.	{ Farm-yard manure; almost podding }	45.8	73.14	10.26	16.60	26.86
July 15.	{ Unmanured; almost podding }	25.9	82.63	15.83	1.54	17.37
July 15.	{ Mineral and ammo- niacal manure; al- most podding }	30.9	70.55	20.71	8.74	29.45

The general accordance in the proportions of nitrogen throughout this series, together with their general approximation to the amounts observed in the preceding series, and the consequent similarity in the range of the sums of the two remaining gases—

carbonic acid and oxygen—point to the character of the change by virtue of which the proportion of carbonic acid is diminished, and that of oxygen increased. The variations are, nevertheless, somewhat considerable; nor do we feel confidence in referring them to any other than accidental causes. There can be no doubt, however, that the carbonic acid shown to exist in the plants in the shade yields the oxygen evolved in the sunlight.

The results which follow will show the influence of the time of action of the sunlight on the plant, upon the relative proportions of carbonic acid and oxygen.

Duplicate quantities of plant were operated upon, both being prepared in the shade; the vessels were then excluded from the light by means of a thick paper covering; and, in this condition, each was attached to a Torricellian exhaustor (the apparatus above described). The covering being then removed from one of the vessels, exposing it and its contents to the direct rays of the sun, and the other remaining covered, the exhaustion of both was then commenced immediately, and the action continued for half-an-hour. The following results were obtained in this manner:—

TABLE X.

Date.	Description of plant.	Conditions during exhaustion.	Total gas collected.	Per cent.			
				Nitrogen.	Oxygen.	Carbonic acid.	Oxygen and carbonic acid.
(1858)			cub.cents.				
	Beans.	{ In dark ..	25·7	66·93	2·33	30·74	33·07
		{ In sunlight	36·4	69·78	8·24	21·98	30·22
July 22.	Oats.	{ In dark ...	28·3	81·63	3·53	14·84	18·37
		{ In sunlight	25·9	70·27	13·13	16·60	29·73
July 23.	Oats.	{ In dark ...	26·4	73·11	8·33	18·56	26·89
		{ In sunlight	22·7	72·25	16·74	11·01	27·75
July 23.	Oats	{ In dark ...	27·4	68·25	5·11	26·64	31·75
		{ In sunlight	29·2	67·47	19·86	12·67	32·53
July 23.	Oats.	{ In dark ...	31·4	77·39	6·69	15·92	22·61
		{ In sunlight	21·7	76·50	16·59	6·91	23·50

The results clearly indicate the ready transformation, in sunlight, of carbonic acid into a solid carbon-compound and free oxygen; and they have an important bearing on the question under con-

sideration, showing, as they do, the powerful reducing action exerted upon the carbonic acid under the influence of the sun's rays.

The experiments next cited were arranged to show whether the reduction of the carbonic acid was more probably due to the action of the sunlight at the moment of the passage of the gas through the walls of the cell, or whether the oxygen were liberated within the growing cell. Duplicate portions of plant were prepared exactly as in the experiments last referred to, and both were kept in the dark for some time before commencing the exhaustion; then, one being still covered, and the other exposed to sunlight, both were submitted to exhaustion for four or five minutes only, increased quantity of plant being operated upon in order to obtain sufficient gas during this short period. Table XI gives the results so obtained :—

TABLE XI.

Date.	Description of plant.	Conditions during exhaustion.	Total gas collected.	Per cent.			
				Nitrogen.	Oxygen.	Carbonic acid.	Oxygen and carbonic acid.
(1858)			cub.cents.				
July 30.	Oats.	{ In dark ... In sunlight	41·7 42·6	72·42 72·23	3·60 4·71	23·98 23·06	27·58 27·77
July 30.	Oats.	{ In dark ... In sunlight	55·7 43·3	71·46 69·98	3·23 3·23	25·31 26·79	28·54 30·02
July 30.	Oats.	{ In dark ... In sunlight	37·9 38·5	83·11 77·14	6·86 9·09	10·03 13·77	16·89 22·86
July 31.	Oats.	{ In dark ... In sunlight	34·4 41·8	78·49 75·84	7·27 7·89	14·24 16·27	21·51 24·16

It would appear that carbonic acid can pass through the cell-wall under the influence of sunlight without suffering decomposition, and hence that the oxygen yielded by a plant which has been for some time exposed to the direct rays of the sun, existed as such in the cell before the exhaustion. The slight preponderance of oxygen in the gas exhausted in sunlight was doubtless due to its action upon the carbonic acid within the cell during the short period of the operation, just as when the plant is subjected to ordinary atmospheric pressure.

In order to bring out more clearly the influence of sunlight before the exhaustion, experiments were made in which duplicate quantities of plant were each covered for some time, the paper was then removed from one, and then, after an interval of from 20 to 30 minutes, the exhaustion of both was commenced, and continued for 10, 15, or 20 minutes. The following results were obtained:—

TABLE XII.

Date.	Description of plant.	Conditions before and during exhaustion.	Total gas collected.	Per cent.			
				Nitrogen.	Oxygen.	Carbonic acid.	Oxygen and carbonic acid.
			cub. cents.				
July 31.	Oats.	{ In dark ...	24.0	77.08	8.75	19.17	22.92
		{ In sunlight	34.5	68.69	24.93	6.38	31.31
August 2.	Oats.	{ In dark ...	18.6	68.28	10.21	21.51	31.72
		{ In sunlight	39.2	67.86	25.25	6.89	32.14
August 2.	Oats.	{ In dark ...	30.7	76.87	8.14	14.99	23.13
		{ In sunlight	26.5	69.43	27.17	3.40	30.67
August 2.	Oats.	{ In dark ...	17.0	79.41	7.65	12.94	20.59
		{ In sunlight	28.6	76.22	18.53	5.25	23.78
August 3.	Oats.	{ In dark ...	29.8	81.88	6.38	11.74	18.12
		{ In sunlight	32.1	66.36	30.53	3.11	33.64
August 3.	Oats.	{ In dark ...	11.6	65.52	6.90	27.58	34.48
		{ In sunlight	23.1	70.56	20.35	9.09	29.44
August 3.	Oats.	{ In dark ...	17.0	80.00	5.88	14.12	20.00
		{ In sunlight	19.7	73.10	22.33	4.57	26.90

The comparison of these results with those in Table XI, together with a consideration of the fact that, as soon as the pressure was removed, the gas was evolved from all parts of the leaf, and not from the surrounding water, shows that the oxygen must have been liberated and retained within the cells until the instant of exhaustion.

The results of this part of the enquiry may be briefly summed up as follow:—

1. Carbonic acid, within growing vegetable cells and intercellular passages, suffers decomposition very rapidly on the penetration of the sun's rays, oxygen being liberated, and remaining within the plant, or being evolved from it.

2. Living vegetable cells, in the dark, or not penetrated by the direct rays of the sun, consume oxygen very rapidly, carbonic acid being formed.

3. Hence, the proportion of oxygen must vary greatly, according to the position of the cell, and to the external conditions of light; and it will oscillate under the influence of the reducing force of carbon-matter (forming carbonic acid) on the one hand, and that of the sun's rays (liberating oxygen and forming carbon-compounds containing less oxygen than carbonic acid) on the other. Both actions may go on simultaneously, according to the depth of the cell; and, according to the laws in conformity with which the diffusion of gases, and their passage through tissues, take place, the oxygen of the outer cells would be continually penetrating to the deeper cells, and there oxidising carbon-matter, whilst carbonic acid would pass in the opposite direction, and be decomposed under the influence of sunlight in the outer cells; and the once outer cells, as they become more deeply buried, may gradually pass from the state in which the sunlight is the more powerful, to that in which the carbon-matter is the more powerful reducing agent—from the state in which there is a flow of carbonic acid to them, and of oxygen from them, to that in which the reverse action takes place. Thus, oxidised products—acids, saccharine matter, &c.—may be formed in the deeper cells, and in the outer cells more highly carbonised substances, which, in their turn, become oxidised when buried deeper.

4. The great reducing power operating in those parts of the plant where ozone is most likely, if at all, to be evolved, seems unfavourable to the oxidation of nitrogen; that is, under circumstances in which carbon-matter is not oxidised, but, on the contrary, carbonic acid is reduced, and, when beyond the influence of the direct rays of the sun, the cells seem to supply an abundance of the more easily oxidised carbon matter, should free oxygen, or ozone, be present. Further, on the assumption that nitrates are available as a source of nitrogen to plants,* if it were admitted that nitrogen was oxidated within the plant, it must be supposed (as in the case of carbon) that there are conditions under which an oxygen-compound of nitrogen may be reduced

* In reference to this point, it may be mentioned that several specimens of green wheat and grass, which had been liberally manured with nitrate of soda, were examined for nitric acid, but no trace of it was found in them.

within the organism, and that there are others in which the reverse action, namely, the oxidation of nitrogen, can take place.

5. Bearing upon the questions under consideration, but illustrated by experiments to be referred to further on, it may be stated, that so great is the reducing power of certain carbon-compounds of vegetable matter, that when the growing process has ceased, and all the free oxygen in the cells has been consumed, water is decomposed, and hydrogen evolved; but, as the action does not continue long, it would appear either that the cell-matter loses its reducing power after being slightly oxidized, or, more probably, that the cell provides a certain amount of matter more easily oxidized than the remainder.

The suggestion arises, whether ozone may not be formed under the influence of the powerful reducing action of the carbon-compounds of the cell on the oxygen eliminated from carbonic acid in sunlight, rather than under the direct action of the sunlight itself—that is, in a manner analogous to that in which it is ordinarily obtained by allowing oxygen to come into incomplete or only instantaneous contact with phosphorus? Certain carbon-compounds of the vegetable cell have a great affinity for oxygen in the dark, and the oscillations of the affinities (due to the degree of light and to the depth of the cell) would afford conditions somewhat similar to those under which ozone is produced in the presence of phosphorus. But, even were the action as here supposed, it may be questioned whether the ozone would not be at once destroyed in contact with the carbon-matter present. It is more probable, however, that the ozone said to be observed in the vicinity of vegetation, is due to the intense action of the oxygen of the air upon minute quantities of volatile hydro-carbons emitted by the plants, than to any action within the cells; and it is in favour of this view, that ozone has been observed most readily in the vicinity of such plants as emit freely essential oils.

If ozone be found in any way in connexion with the growing plant, it might be supposed to act in an indirect, if not in a direct manner, as a source of combined nitrogen in experiments on the question of the assimilation of free nitrogen by plants—(1) by oxidating the nitrogen dissolved in the water within the apparatus, (2) by forming nitrates in contact with the moist, porous, and alkaline soil, (3) by oxidating the free nitrogen in the cells of the older roots or that evolved in their decomposition.

With a view to the points above suggested, experiments were made to ascertain the influence of ozonous air upon organic matter, and on certain porous and alkaline bodies, under various circumstances. For the generation of the ozonous atmosphere, three glass carboys, each of about 40 litres capacity, were fitted with stone-ware stoppers, through which glass tubes passed, connecting the three together, the joints being made with calcined gypsum cement. The bottom of each vessel was covered with water to the depth of from a quarter to half an inch, so that, on pieces of phosphorus being dropped in, they were partly covered by the fluid. Another tube, which could be opened or closed at pleasure, was fixed through each stopper for the supply of water and fresh phosphorus, as needed. A gasometer, of 2 cub. feet capacity, was connected by a glass tube with the first of the three vessels, by which means air could be forced through them in a continuous stream. The air, on passing out, was led first through a wash-bottle, and then into a glass vessel, from which, by means of eleven glass tubes passing from it, it was distributed into as many bottles, containing, respectively, the substances to be submitted to the action of the ozone, each bottle being fitted with an exit tube, in which were fragments of pumice, saturated with sulphuric acid. The following were the substances or mixtures operated upon:—

(1) $\frac{3}{4}$ lb. of ignited soil, moistened with 100 cub. centims. water; this being just sufficient to make it slightly coherent.

(2) $\frac{3}{4}$ lb. of ignited soil, 300 cub. centims. water, 2·5 ounces boiled starch, and 2·5 ounces dry starch.

(3) $\frac{3}{4}$ lb. of ignited soil, 200 cub. centims. water, and 2·5 ounces sawdust.

(4) 2·5 ounces sawdust, and 100 cub. centims. water.

(5) $\frac{3}{4}$ lb. of ignited soil, 200 cub. centims. water, and 2·5 ounces bean-meal.

(6) $\frac{3}{4}$ lb. of ignited soil, 150 cub. centims. water, and 2·5 ounces bean-meal.

(7) 2·5 ounces bean-meal, and 50 cub. centims. water.

(8) 1 lb. garden soil.

(9) $\frac{3}{4}$ lb. of slaked lime, and 2·5 ounces bean-meal, made slightly pasty with water.

(10) $\frac{3}{4}$ lb. of slaked lime, some starch, and sawdust, made slightly pasty with water.

(11) 2·5 ounces of boiled starch, 2·5 ounces fresh starch, and 200 cub. centims. water.

All the bottles stood before a window where the sun shone directly upon them most of the day, as it did also for some hours on the balloons. The experiment commenced in April, and continued through the summer and part of the autumn, and the thermometer in the room frequently stood at 25° to 29° C. About 9 o'clock every morning, and once or twice more during the day, the cylinder of the gasometer was raised, and by its gradual depression a slow current of air was passed through the apparatus during about two hours. The amount of ozone passed was so great, that vulcanised caoutchouc tubing, first used for the joint with the tube of the wash-bottle, was cut off by the passage of a few gasometerfuls of air; and the joint was then made by means of a piece of larger glass tubing passed over the point of contact of the tubes to be connected, and closed at the ends with rings of cork well fitted upon the smaller tubes. Every three or four days a small piece of phosphorus was dropped into each balloon.

Until the beginning of July the wash-bottle was filled with large lumps of pumice, and about half full of a solution of caustic potash, which, by the rapid bubbling of the ozonous air through it, kept the pumice moist. An examination of this liquid, with the washings of the pumice, failed to show any trace of nitric acid. From the beginning of July, the alkaline wash was replaced by pure water, and, at the termination of the experiment, these washings also gave no indication of nitric acid.

At the termination of the experiment, a portion of each substance or mixture was exhausted with water, and the extract concentrated by boiling, after the addition of permanganate of potash to destroy the organic matter. The excess of permanganic acid was removed by carbonate of lead, and the clear solution filtered off and tested for nitric acid; but in no case, excepting that of the garden soil (which examination showed to contain it before being subjected to the action) was there any indication of its presence.

It is not, indeed, hence inferred, that under no circumstances can nitric acid be formed by the action of ozone, on nitrogenous compounds of the ammonia class, or the nascent nitrogen evolved from them, or even in connexion with non-nitrogenous bodies, or porous substances permeated with gaseous nitrogen, or in the atmosphere itself; or that the nitric acid in soils is not in part due to some of these actions. But, considering the negative result with large quantities of ozonous air, acting upon organic

matter, soil, &c., in a wide range of circumstances, and for so long a period, it is believed that no error in the results of the experiments on the assimilation of free nitrogen by plants will arise from the action of ozone upon free nitrogen, providing to the plants an unaccounted supply of combined nitrogen.

It may be here observed that, if from the recent results of Schönbein, on the formation of nitrogen-compounds under the influence of evaporation, we are to conclude that the evaporation of water by plants during growth is a constant source of such formation, it would be difficult to arrange an experiment on the question of the assimilation of free nitrogen by plants that would not be open to objection; for there must then be always a gain of combined nitrogen in the experiment due to the action supposed. Or, if such formation be the constant result of evaporation from the surface of the globe (whether land or water), the products can hardly be supposed to become in any material degree distributed through the atmosphere: for, independently of the character and condition of the products, the amount of combined nitrogen brought down from it by aqueous deposition in various forms is too small in proportion to that annually available for the vegetation of a given area, to give countenance to such a supposition.

Numerous experiments were made to determine whether free nitrogen was evolved during the decomposition of nitrogenous organic compounds. Two obvious methods of investigation presented themselves:—1, to allow the decomposition to take place under circumstances in which any free nitrogen evolved might be collected and estimated; 2, to collect and estimate the compounds of nitrogen formed, and reckon the loss of nitrogen as free nitrogen evolved.

Reiset, operating according to the first of these methods, submitted nitrogenous animal and vegetable substances to decomposition under an inclosing vessel, into which he passed oxygen as that of the air was consumed, and the result was an increase in the amount of nitrogen. Operating according to the second method, M. G. Ville concluded that, in several cases, about one-third of the nitrogen of the substance submitted to decomposition was evolved in the free state. Again, as already shown, M. Boussingault found a loss of nitrogen in his experiments on the assimilation of free nitrogen by plants when he used nitrogenous organic matter as manure.

In our own experiments, a given weight of nitrogenous organic matter, the percentage of nitrogen in which was determined, was mixed with burnt, washed, and re-ignited soil, or pumice, and put into a bottle of about 360 cub. cents. capacity (see B, plate I. fig. 8), and a proper quantity of water added. The bottle was closed with a cork, through which two bent glass tubes passed, externally in opposite directions, one connected with an eight-bulbed apparatus, A, containing sulphuric acid, and the other with a similar apparatus, C, containing a solution of oxalic acid, from which passed a bent tube, extending, through a cork, to the bottom of a second bottle, D, containing sulphuric acid; and through the cork of the bottle D another tube, E, also passed, but did not dip into the acid. On drawing air at E, a current was established inwards through the sulphuric acid in A, by which it was washed free from ammonia, through the bottle B with the decomposing organic matter, through the oxalic acid in C, by which the absorbable gaseous products were retained, and so on. At the termination of the experiment, the combined nitrogen remaining in B, and that absorbed by the oxalic acid in C, being determined, the amount of nitrogen given off in the free state was estimated by difference.

In 1857, six experiments were made, two with wheat-meal, two with barley-meal, and two with bean-meal, known quantities of each being mixed, respectively, with about 100 grammes of prepared soil, or about 60 grammes of prepared pumice, the mixtures filling the bottles B to the depth of about two inches, and sufficient water being added to bring the mass into an agglutinated condition. The six sets of apparatus were placed before a large window, where, during the middle of the day, the sun shone directly upon them. Several litres of air were drawn, by the mouth, through each apparatus daily; and the experiment was continued from June 10 to October 8. After a day or two, the gas had a more or less disagreeable taste, and the odour of decomposing organic matter. The following statement condensed from the notes taken, shows the condition of the several mixtures at the termination of the experiment:—

1. Wheat-meal and pumice.—Slightly mouldy; odour of decomposing organic matter; quite moist, particles of pumice adhering together.

2. Wheat-meal and soil.—Slightly mouldy on the surface;

odour as No. 1; the mass moist, but not sufficiently so for the particles of soil to agglutinate.

3. Barley-meal and pumice.—Not mouldy; odour like Nos. 1 and 2, but more intense, and sour, like fermenting malt; the mass wet and clammy.

4. Barley-meal and soil.—Not mouldy; odour like No. 3; sufficiently moist to agglutinate.

5. Bean-meal and pumice.—A little mould on the surface; odour very disagreeable and putrescent; the mass wet and clammy.

6. Bean-meal and soil.—Very similar to No. 5, but rather more wet and pasty.

In every case, carbonic acid was evolved on the addition of oxalic acid to the mass, preparatory to evaporating to dryness; and the most from the bean-meal with soil. A known proportion, about one-half of each dried mass, was burnt with soda-lime; and the remainder reserved for the determination of nitrates, if present. However, the aqueous extract of the mass in no case indicated nitric acid; though, on then adding 0·001 gramme of nitric acid to the residual mass, and re-extracting with water, its presence was always indicated. The following Table gives the numerical results of the six experiments :—

TABLE XIII.

Substances submitted to experiment.				Nitrogen after decomposition.			
Description of organic matter.	Description of matrix.	Quantity of meal taken.	Quantity of nitrogen.	Total by soda-lime.	Not recovered.		
					Actual quantity.	Per cent.	
		grms.	grms.	grms.	grms.		
1. Wheat-meal	Ignited pumice	2·0585	0·0370	0·0338	0·0032	8·51	
2. Wheat-meal	Ignited soil ...	2·1282	0·0383	0·0335	0·0048	12·53	
3. Barley-meal	Ignited pumice	2 2495	0·0380	0·0368	0 0012	3 16	
4. Barley-meal	Ignited soil ...	2·0980	0·0355	0·0309	0·0046	12 96	
5. Bean-meal...	Ignited pumice	2·0650	0·0803	0·0741	0·0062	7·72	
6. Bean-meal...	Ignited soil ...	2·0800	0·0809	0·0823	(+ 0·0014)	(+ 1·73)	

With one exception (in which the gain of nitrogen is within the range of error of analysis), all the experiments show that a part of

the nitrogen of the decomposing organic matter passed into a state in which it could not be estimated by the soda-lime process. Neither did it exist as nitric acid. It would appear, therefore, that there was an evolution of free nitrogen. But, although so large a proportion of the total nitrogen passed off in some form, yet scarcely a trace of ammonia was given off from the mass; for, on distilling the oxalic acid in C with an excess of caustic potash, in only one case (that of the bean-meal and pumice) was any ammonia indicated, and then it was equal to only 0.002 gramme nitrogen.

The experiments, the results of which are yet to be recorded, were arranged with some reference to the question of the character and extent of the decomposition, and of the part played by water in the process.

In 1858, a set of nine experiments was made, embracing a wide range of conditions as to moisture, in some of which were included the circumstances of germination, early growth, and subsequent decay of the products, and in which the intermediate stages and final extent of decomposition were more closely considered, the former by periodical inspection, and observation on the character of the odour, and the latter by a further examination of the remaining products. Although soil and pumice indicated no special difference of result, both were still used; about 175 to 200 grammes of the former, or 120 to 150 grammes of the latter being employed. Reference to Tables XIV and XV will sufficiently show the other conditions of the several experiments. The description of apparatus was the same as that used in 1857 (fig. 8).

The mixtures with 50 cub. cent. of water added were in the condition of a rather moist soil; those with 40 cub. cent. were much drier, having no tendency to agglutination; and those with 100 cub. cent. were very wet, having some free water above the solid matters. The seeds sown with 50 cub. cent. germinated in a few days, and the bottles, B, were soon filled with vegetable matter (the beans especially developing a very large amount of root, as well as stemmy and leafy matter); but those with 100 cub. cent. water did not germinate, but in a few days showed decomposition. The mixtures of meal and soil also soon showed signs of decomposition, though the odour from them was less foul than from the whole seed and 100 cub. cent. water, which, throughout, were the most disagreeable; and it may be observed that the water at first resting above the solid matters disappeared so rapidly, with active decomposition, as to lead to the conclusion

that some of it was consumed in the process. There was in no case any ozone re-action to test paper. With these few general remarks, we may omit here a record of the detailed observations periodically made on the progress of the decomposition; adding only, that on July 1st (the experiments having commenced in January) 100 cub. cent. of water were added to each, and on August 28th, when the experiment was terminated, there still remained, in all the cases, a layer of from $\frac{1}{4}$ to $\frac{1}{2}$ an inch of fluid over the solid matter, the condition of which was as follows:—

Wheat (a)—Seeds, in soil, with 50 cub. cent. water: very little odour, and not unpleasant; supernatant fluid colourless; the organic matter thoroughly decomposed, only slight remains of stems and leaves being visible. The addition of oxalic acid to the mass, preparatory to evaporation to dryness, caused a copious evolution of carbonic acid.

A similar evolution of carbonic acid took place in every one of the experiments.

Wheat (b)—Seeds, in pumice, with 100 cub. cent. water: supernatant fluid colourless; a disgusting mouldy odour, the form of the grain retained, but the contents disappeared, and the husks filled with fluid.

Wheat (c)—Meal, in soil, with 40 cub. cent. water: supernatant fluid of a yellowish colour and muddy; the mass emitted a foul, disagreeable odour, though less intense than that of the corresponding barley.

Barley (a)—Seeds, in soil, with 50 cub. cent. water: the organic matter thoroughly decomposed; stems, roots, and leaves no longer distinguishable; other conditions much as wheat (a).

Barley (b)—Seeds, in pumice, with 100 cub. cent. water: supernatant fluid clear; the pumice covered with a black coating of organic matter; the odour of the air above the mixture exceedingly disgusting, resembling that of decaying human excrements; traces of sulphide of hydrogen perceptible; the form of the seeds preserved, but the husks contained only fluid.

Barley (c)—Meal, in soil, with 40 cub. cent. water: supernatant water yellowish; odour musty, but not very disagreeable; very slight traces of organic matter perceptible.

Bean (a)—Seeds, in soil, with 50 cub. cent. water: the organic matter well decomposed; odour musty.

Bean (b)—Seeds, in pumice, with 50 cub. cent. water; only

very indefinite skeletons of stems, leaves, and roots remaining; odour musty, but not disagreeable.

Bean (c)—Meal, in soil, with 40 cub. cent. water; supernatant fluid slightly yellow; odour musty, but not offensive.

After drying with oxalic acid, any slight remains of organic matter had become brittle; and in every case, excepting where 100 cub. cent. of water had been originally added (when the husks remained visible), the mass had the appearance of clean soil, or pumice, without organic matter.

In a few instances, the sulphuric acid in D became slightly brown, indicating the passage into it, through the oxalic acid, of some more complex carbon-compound than carbonic acid; and we have observed phenomena of a similar kind in some other cases.

The following Tables, XIV and XV, show the conditions of the several experiments, and the numerical results obtained, the former relating more particularly to the amount and proportion of the original *carbon*, and the latter to those of the original *nitrogen*, remaining after the decomposition, or given off during the process:—

TABLE XIV.

Substances involved in the experiment.				Weight of organic matter.		Carbon.			
Organic matter.		Matrix.	Water added.	Fresh.	Dry.	Before decomposition.	After decomposition.	Loss in decomposition.	
Description.	Condition.							Actual quantity.	Per cent.
			cub. cent.	grms.	grms.	grms.	grms.	grms.	
1. Wheat	a. 171 seeds	Ignited soil....	50	8.0475	6.7438	3.1089	0.9274	2.1815	70.17
	b. 171 seeds	Ignited pumice	100	8.0718	6.7639	3.1183	0.9178	2.2004	70.56
	c. Meal....	Ignited soil....	40	9.8810	8.2803	3.8172	1.2199	2.4973	65.42
2. Barley	a. 163 seeds	Ignited soil....	50	8.0440	6.7127	3.0523	0.9598	2.0925	68.55
	b. 163 seeds	Ignited pumice	100	8.1360	6.7895	3.0872	1.1952	1.8920	61.28
	c. Meal....	Ignited soil....	40	8.9671	7.4630	3.4025	1.0995	2.3030	67.68
3. Beans	a. 7 seeds...	Ignited soil....	50	5.7830	4.5830	2.2915	0.8511	1.4404	62.06
	b. 7 seeds...	Ignited pumice	50	6.4700	5.1275	2.5637			
	c. Meal....	Ignited soil....	40	6.1750	4.8937	2.4468	0.9778	1.4690	60.04

TABLE XV.

Substances involved in the experiment.				Total nitrogen.				Nitrogen obtained as ammonia by distillation with weak alkali.			
Organic matter.		Matrix.	Water added.	Before decomposition.	After decomposition.	Loss (or gain).		From oxalic acid in C.		From total products.	
Description.	Condition.					Actual quantity.	Per cent.	Actual quantity.	Per cent.	Actual quantity.	Per cent.
			cub. cent.	grms.	grms.	grms.		grms.		grms.	
1. Wheat	a. 171 seeds	Ignited soil....	50	0.1392	0.1398	+0.0006	+0.43	0.00038	0.273	0.0429	30.83
	b. 171 seeds	Ignited pumice	100	0.1396	0.1314	0.0182	13.08	0.00002	0.014	0.0673	41.06
	c. Meal....	Ignited soil....	40	0.1709	0.1680	0.0029	1.74	0.00040	0.234	0.0197	11.49
2. Barley	a. 163 seeds	Ignited soil....	50	0.1247	0.0746	0.0501	40.30	0.00055	0.441	0.0157	12.64
	b. 163 seeds	Ignited pumice	100	0.1261	0.1052	0.0209	16.52	0.00002	0.016	0.0294	23.39
	c. Meal....	Ignited soil....	40	0.1390	0.1311	0.0079	5.66	0.00039	0.280	0.0166	11.97
3. Beans	a. 7 seeds...	Ignited soil....	50	0.2417	0.2107	0.0310	12.84	0.00341	1.424	0.0140	57.91
	b. 7 seeds...	Ignited pumice	50	0.2704	0.2380	0.0324	11.99	0.00242	0.895		
	c. Meal....	Ignited soil....	40	0.2581	0.2267	0.0314	12.16	0.00080	0.232	0.1039	40.25

The results in Tables XIII and XV are mutually confirmatory in their more general indications; and they agree in showing no tangible relation between the nitrogen-products and the varied circumstances of decomposition. In some cases there has been no, and in others very great, evolution of free nitrogen—so great, indeed, that we made repeated analyses to satisfy ourselves of the truth of the result.

The physical condition of the several substances at the termination of the experiment, as also the comparative uniformity in the proportion of carbon given off (see Table XIV), might lead to the conclusion that the decomposition had proceeded about equally far in all cases; but whilst the proportion of carbon given off ranged between 60 and 70 per cent. of its original amount, that of the nitrogen varied coincidentally from 0 to 40 per cent. of the original amount. Again, the proportion of the nitrogen which was retained in the mass, or absorbed in the oxalic acid in C, in such form as to be given off as ammonia on distillation after being rendered weakly alkaline, and which probably existed, therefore, in the products as ammonia, ranged from 12 to 58 per cent. of the total quantity involved in the experiment; whilst the proportion evolved from the mass during the decomposition and retained in the oxalic acid solution (C), varied from 0 to about 1.5 per cent. of the original amount. There would seem, in fact, to be no relation between the loss of carbon, the loss of nitrogen, the formation of ammonia, and the evolution of it from the mass during decomposition, on the one hand, and the circumstances of

matrix, moisture, growth, decay, &c., on the other, which can with safety be considered as exhibiting cause and consequence.

It may, however, be concluded, that under particular, and apparently rare circumstances of the decomposition of nitrogenous organic matter, there is no loss of nitrogen evolved in the free state, but that, under a wide range of circumstances, a considerable loss of nitrogen takes place; and whilst the proportion of the nitrogen taking such form that it may be driven off as ammonia on the distillation of the products with a weak alkali-solution, varied from one-eighth to more than one-half of the total, the amount evolved from the mass as ammonia during decomposition was quite inconsiderable.

Independently of the importance of these facts, considered in connexion with the conditions which may be involved in an experiment on the question of the assimilation of free nitrogen by plants, it is obvious that they have a very important bearing on the practical question of the management of the manure-heap, and as such, require further investigation to ascertain the causes of the differences of result manifested, in order, if possible, to control them. The results also point to the probable insignificance of the loss of nitrogen from decomposing manure in the form of ammonia, a supposed evil to which the attention of agricultural chemists has been especially directed, whilst the apparently much larger loss, as free nitrogen, has not at all been considered.

The question arises, what is the character of the action by which nitrogenous compounds are decomposed with the evolution of free nitrogen? It may be—(1) of an oxidising character analogous to that of chlorine on ammonia; (2) of a reducing character similar to that of many substances upon the oxygen compounds of nitrogen; (3) these two actions may operate in succession the one to the other.

The nitrogen in the organic substances submitted to decomposition, doubtless existed in a condition more analogous to a hydrogen, than to an oxygen-compound of it; and the researches of Hofmann would lead us to suppose that the nitrogen-compounds in question were of the ammonia class. They are more difficult to oxidize into nitric acid than is ammonia, but their transition into ammonia is extremely easy; and, since ammonias yield free nitrogen under the influence of oxidising forces, it may be inferred that it has been under the influence of such forces that the nitrogen has been set free in the experiments recorded. Pelouze

has remarked* that nitrates are converted into ammonia in contact with decomposing organic matter; and experiments of our own have shown that, during the decomposition of organic matters in contact with nitrates, free nitrogen is not evolved.

The experiments next referred to bear upon these points.

After several qualitative experiments, on a smaller scale, about half a pound of a mixture of wheat, barley, and beans, was put into the long narrow glass vessel of about 500 cub. cents. capacity (plate I, fig. 7), which was then filled with well-boiled water, and closed with a cork, through which two glass tubes (*a* and *b*) passed, the ends of which were fitted with caoutchouc tubing, for closing with pinchcocks, or connexion with the Torricellian exhauster. The vessel having been so connected with the exhauster for several hours, to remove the gaseous nitrogen from the seeds, it was then inverted in mercury, the tube *b* opened under that fluid, and the whole placed in sunlight to favour decomposition. This was done on August 28 (1858); the seed soon swelled, and on August 30 well-marked decomposition had set in. On September 13, the vessel was about two-thirds full of gas, and so much water was displaced, that part of the seed was above the remaining water, in the gas, which commenced bubbling out through the tube *b*. The arrangement so remained until October 5, when 400 cub. cents. of gas were collected, of which the percentage composition was as follows:—

	Carbonic Acid.	Hydrogen.	Nitrogen.
Experiment 1	64·87	34·83	0·30
Experiment 2	64·54	35·46	traces

The quantity of gas evolved points to the extent of the decomposition; the amount of carbonic acid and hydrogen shows how great must have been the reducing force exerted; and the small quantity of nitrogen, which was probably due to accident, indicates that free nitrogen was not a product of the action.

The vessel was again filled with boiled water, again connected for some time with the Torricellian exhauster, and again placed in its former position in the sunlight. On November 17, only a few bubbles of gas having been evolved, the vessel was removed into a room, the temperature of which varied from a few degrees above the freezing point to about 24° C. On December 12, the gas

* Comptes Rendus, xliv, p. 118.

collected without exhaustion measured only 6.1 cub. cents., of which 4.6 were absorbed by potash, and the remainder was combustible and contained no appreciable amount of free nitrogen.

Five grammes of nitrate of potash were now put into the vessel (with the same organic matter), and it was replaced in the room as before. On May 25, 1859, the vessel having been heated up to 30° C. several times during the interval, only 4 cub. cent. of gas were collected, one-fourth of which was carbonic acid, and the remainder combustible.

The vessel was now placed in sunlight again, but up to the middle of June no more gas was evolved. The fluid still contained nitrate. The vessel was now half-filled with oxygen; but after ten days not one-fourth of the supplied oxygen had been consumed.

The total gas being removed, oxygen was conducted into the vessel until the greater part of the fluid was driven out, leaving the partly decomposed seeds in an atmosphere of this gas. The apparatus so arranged was placed in the sunlight, and remained there during some very warm weather, when, on July 12, the gas collected contained in 100 parts—carbonic acid 20, oxygen 79, nitrogen 1; but as, by accident, a little air had been admitted into the vessel, the small quantity of nitrogen found may be attributed to it.

On removal, the beans were found to possess much of their original firmness; but the other seeds, though retaining their form, were softer, and had evidently undergone more complete decomposition. Very little odour was emitted, and it was not unpleasant.

It is obvious that there had been no evolution of free nitrogen during the long period that these matters had been submitted to decomposition under the conditions described.

Experiments were also made upon the products of the decomposition of organic matter in the first stages of the process. The decomposition took place in water, in the tall glass vessels already described. In Table XVI are given the amounts, and the composition, of the gas obtained in a few out of numerous experiments; and, for comparison, some of the results already referred to are included.

TABLE XVI.

Description of Organic matter subjected to decomposition.	Total gas collected.	Composition of the gas, per cent.		
		Carbonic acid.	Hydrogen.	Nitrogen.
	cub. cents.			
a. Wheat, Barley, and Bean seed ...	400	64·87	34·83	0·30
b. Turnip plant; root with leaves.	168·2	64·54	35·46	traces.
c. Turnip plant; root with leaves.	162·2	76·23	22·91	0·87
d. Turnip plant; root with leaves.	123·6	68·83	23·93	7·24
e. Turnip plant; root with leaves.	41·2	68·06	25·63	6·31
		67·52	25·43	7·05
		64·95	14·66	20·39

Experiment (a) is the one described above. In all the other cases, about two ounces of plant were operated upon. The experiment commenced on August 29, and was stopped on October 5, when the structure of the plant was almost entirely destroyed, there remained only a mass of decomposed matter at the bottom of the vessels, and the evolution of the gas had entirely ceased. The plant (b) was exhausted of its gas before exposure; and, under these circumstances, a very small quantity of free nitrogen was found at the termination of the experiment, whilst plants c, d, and e, which were not so exhausted, gave a larger amount of free nitrogen; and, although in experiment (e) the percentage of nitrogen was much higher than in the other cases, the total quantity of gas was much less, and the actual quantity of nitrogen was nearly the same in the several cases, leading to the supposition that it existed within the plant at the commencement of the experiment.

The result is, then, that, in the absence of free oxygen, no free nitrogen was evolved from the decomposing nitrogenous compounds, and it may be inferred that the loss of nitrogen indicated in Tables XIII and XV was the result of an oxidising process.

Some experiments were also made in which the plan was to place nitrogenous organic matter in an atmosphere of pure oxygen, and to afford a constant supply of the gas as it was consumed and the carbonic acid produced was absorbed by a solution of caustic potash. The results obtained indicated an evolution of free nitrogen; but owing to the difficulty of getting the requisite apparatus absolutely air-tight, they were open to some exception, and the investigation was, for the time, abandoned.

It is obvious that the results recorded point to a serious difficulty in the conduct of experiments on the question of the assimilation of free nitrogen by plants; for although, as Boussingault has shown, there may be no loss of nitrogen during germination, yet, during the entire period of growth of a plant, portions of nitrogenous organic matter may be subject to decomposition under conditions favourable to the evolution of free nitrogen.

The following experimental results are interesting in connexion with this point. Eight seeds, each, of wheat, barley, and oats, were respectively sown in prepared soil, precisely as in the experiments on assimilation. The three pots were placed under a glass shade, 16 inches in diameter, which rested in the groove of a stoneware lute-vessel containing sulphuric acid. About 500 cub. cent. of distilled water were added to each soil at the commencement, but no carbonic acid was supplied beyond that which might be contained in the water. The pots, enclosed as described, were then exposed to the diffused light of the laboratory, but without the access of direct sunlight. In a few days, all came up, and grew very rapidly in height, but with little development and expansion of leaf; all the plants being tall, slender, and delicate, and having the pale green colour common to plants in deficient sunlight. In other experiments, plants in this condition, when removed into sunlight, ceased the predominant upward tendency of growth, the long delicate first leaves lost their vitality, numerous shorter and broader ones were formed, and the stems became thicker and more dense.

The experiment under consideration commenced on May 17, 1858, and continued until June 10 (24 days), when the plants had ceased to grow. All the plants were much alike; ranging from 7 to 12 inches in height, each having three leaves, two lateral ones from 8 to 12 inches long, and a shorter, unrolled terminal one. The stems of several were so slender and delicate as to fall over. The roots were found to consist of short fibrils, with divaricated branchlets, seldom extending more than 2 or 3 inches from the seed. Table XVII gives the analytical results of the experiment:—

TABLE XVII.

Particulars of seed sown.			Particulars of the products.						
	Dry matter.	Nitrogen.	Dry vegetable matter.			Nitrogen.			
			Stems.	Roots.	Total.	In stems & roots.	In soil & pot.	In total products.	Gain or loss.
	gram.	gram.	gram.	gram.	gram.	gram.	gram.	gram.	gram.
Wheat	0.4077	.00790	.320	.140	.460	.00697	.0012	.00817	+ .00027
Barley	0.3234	.00573	.290	.160	.450	.00570	traces	.00570	- .00003
Oats...	0.2900	.00640	.355	.060	.415	.00640	traces	.00640	+ traces

Let the accuracy of the result in regard to the nitrogen should be endangered, the roots were but slightly washed, and retained particles of soil, in consequence of which the weights given for their dry matter are a little too high. There was, however, evidently a slight gain of dry matter, the carbon of which was doubtless due to carbonic acid in the distilled water which had been supplied. The rapid growth, its short duration, the limited distribution of the roots, and the fact that no water was added during growth, which might distribute easily transportable matters, are conditions which are all consistent with the almost total absence of nitrogen in the soil.

The last column in the Table (XVII) shows that in these experiments no free nitrogen was given off during the process of germination and growth; at least the assumption that free nitrogen was evolved implies the still more improbable one that an exactly equal amount of free nitrogen was assimilated.

It would appear, therefore, that in an experiment on the question of the assimilation of free nitrogen by plants, little fear of loss of nitrogen, due to the decomposition of nitrogenous organic matter, need be entertained, so long as that matter is subjected to the ordinary process of germination, and exhaustion to supply materials for growth; though there may be considerable danger of such loss if nitrogenous organic matter were used as manure, or in case of the decomposition of sterile seeds, dead leaves, old roots, or nitrogenous excretions. In judging, according to the conditions of the assimilation experiment, of the probable extent of such evolution, it should be borne in mind that, in the cases where the large evolution of free nitrogen took

place in the experiments on decomposition, the organic matters were subjected to the action for a period of about six months, during which time their organic form was generally entirely destroyed, and they lost nearly three-fourths of their carbon.

One more collateral point requires to be noticed before entering upon the consideration of the direct experiments on the question of assimilation.

Results quoted above leave no doubt of the evolution of hydrogen during the decomposition of organic matter, and Mulder,* and others, have attached much importance to the mutual action of nascent hydrogen so evolved, and gaseous nitrogen, as a source of ammonia. That nascent hydrogen may, under certain circumstances, combine with gaseous nitrogen, has long been admitted; but the view that such combination takes place when hydrogen is evolved from decomposing organic matter, requires confirmation. If but a small part of the hydrogen evolved in the decomposition of organic matter in peat-bogs, in cesspools, in stagnant water, in the annual deposits of leaves in the extensive forests in different parts of the world, decaying under the influence of moisture and confined air between the succeeding layers, as well as in many soils, were to combine with free nitrogen, how enormous would be the amount of ammonia formed in this way—the amount due alone to the decomposition of the exuberant growth of former geological periods would be incalculable.

The results which have been given show, that in the decomposition of nitrogenous organic matter, both free hydrogen and free nitrogen may be given off; and the assumption that nascent hydrogen under such circumstances unites with the nitrogen of the air, implies that it was capable of uniting with free nitrogen under circumstances in which its affinities were not sufficiently powerful to prevent nitrogen-compounds, very similar to ammonias, from giving up nitrogen in the free state; and also that it could act upon ordinary nitrogen when it could not do so upon the nascent nitrogen of the decomposing nitrogenous body. Or, if it did act upon the latter, there would either be no free nitrogen evolved, or if there were, it would show that less nascent nitrogen had been converted into ammonia than had been liberated from its combinations, the result of which would be a loss, and

* Chemistry of Vegetable and Animal Physiology, pp. 111-114, 149-152, &c.

not a gain of combined nitrogen. But the fact is that both free hydrogen and free nitrogen are given off.

It would seem from the above considerations, that there need be little apprehension of error in the results of experiments on the question of assimilation arising from an unaccounted supply to the plants of ammonia formed under the influence of nascent hydrogen given off in any decomposition of the organic matter involved in the experiment.

Having described the arrangement adopted in our experiments on the question of the assimilation of free nitrogen by plants, and discussed some collateral points, particularly those which relate to the possible sources of gain or loss of combined nitrogen to the plants under experiment, it only remains further to preface the statement of the experimental results obtained, by considering what are the most probable conditions for the assimilation of free nitrogen, provided it can take place at all?

The questions arise—whether such assimilation would be most likely to take place, when the plant had no other supply of combined nitrogen, than that in the seed sown, when supplied with a limited amount of combined nitrogen, or with an excess of combined nitrogen? And again—whether at an early stage of growth, at the most active stage, or when the plant is approaching maturity? Combinations of these several circumstances might give a number of special conditions, in perhaps but a few of which assimilation of free nitrogen could take place, if in any.

It would hardly be supposed that free nitrogen would be assimilated when an excess of combined nitrogen was at the disposal of the plant. It is obvious, however, that a wide range of conditions would be experimentally provided, if, in some instances plants were supplied with no more combined nitrogen than that contained in the seed sown, in others they were brought to a given stage and activity of growth by means of limited extraneous supplies of combined nitrogen, and in others the supply of combined nitrogen were still more liberal. It has been sought to provide these several conditions in the experiments under consideration. In either case supposed above, the plant will, at a certain stage, or at certain stages, as the case may be, have an excess of combined nitrogen at its disposal in relation to its immediate wants, and will pass from this point through all stages in regard to supply, to that in which combined nitrogen is in defect. If, how-

ever, the plant cannot assimilate free nitrogen unless it has attained a certain vigour or stage of growth, it may, perhaps, be alleged, in case of no assimilation taking place, that the supply of combined nitrogen has been insufficient to bring it to the supposed point; but if, on the contrary, the assimilation can take place at all periods of growth, and in the absence of all extraneous sources of combined nitrogen, the solution of the question becomes much more easy. Indeed, even in an experiment without any extraneous supply of combined nitrogen, all the conditions with regard simply to the relative quantity of combined nitrogen, are provided. Thus, when the seed is first sown, it contains within itself an excess of combined nitrogen so far as the immediate wants of the plant are concerned, and it will gradually pass to the point at which all available combined nitrogen has been appropriated, and only free nitrogen is presented to it. A negative result under such circumstances even, would afford evidence against assimilation of free nitrogen under a wide range of conditions; and a similar result with various amounts of combined nitrogen supplied, would be conclusive as to a still wider range of circumstances of growth.

The last point for consideration is as to the selection of the plants to submit to the adopted conditions of the experiment. It was sought—(1) to have such as would be adapted to the conditions of temperature, moisture, &c., to which they were to be subjected; (2) to have such as were of importance in an agricultural point of view; (3) to acquire the means of studying any difference, in reference to the point in question, between plants belonging, respectively, to the two great natural orders, the Graminaceæ and the Leguminosæ, which, in some points of view, appear to differ so widely in their demands upon combined nitrogen provided within the soil; (4) to take such as had already been experimented upon, with such conflicting results, by M. Boussingault and M. G. Ville.

Experiments in which the Plants had no other supply of Combined Nitrogen than that contained in the Seed sown.

Table XVIII, p. 74, gives, at one view, a summary of the numerical results obtained under this head; see also figs. 1—6, plate III, which are reduced from careful drawings of six out of the nine Graminaceæ experimented upon, and illustrate the

character and extent of growth attained under the conditions in question.

After so full a discussion of the circumstances under which the results were obtained, but little more is needed in pointing out their bearings upon the question at issue, than to direct attention to the column showing the gain or loss in each experiment.

The differences between the results obtained with soil and with pumice as matrix, in 1857, are not such as can be attributed in any way to the difference of matrix; indeed, the parallel experiments with the two descriptions of soil may be considered as duplicates.

Graminaceous Plants.

It is seen that the largest gain of nitrogen in the three experiments with Graminaceæ, in 1857, was 0·0026 gramme. In regard to the fact that there was generally a somewhat larger gain of nitrogen in some of the experiments in 1857 than in those in 1858, it may be observed that, soon after watering with the fluid drawn off from the surface of the slates used in the former year as lute-vessels, the soils in one or two cases became more or less covered with a slight coating of green matter. And nearly all the slates were found at the end of the experiment to have a similar coating beneath the pans in which the pots stood; whilst, in the experiments of 1858, when glazed earthenware lute-vessels were employed, no such phenomenon was observed. Keeping in view this fact, and considering that so small an amount of nitrogen had to be determined in so large an amount of soil (0·003 gramme or less of nitrogen in about 1,500 grammes of soil), it seems more than questionable whether the small gain above quoted, should not be attributed to errors of experiment or analysis. In fact, we can but conclude, that under the circumstances of growth of the Graminaceous plants to which Table XVIII relates, there has been no assimilation of free nitrogen. There is, indeed, in no case more nitrogen in the plant itself than in the original seed, the gain appearing only when that in the soil and pot is taken into account.

The experiments on germination and growth referred to at pp. 68-9, showed how completely the plants could appropriate the nitrogen of the seed, leaving only traces in the soil; and the experiments on decomposition showed how complete was the action coincident with the passage of any large proportion of the

TABLE XVIII.

Results of Experiments to determine whether Plants supplied with no combined Nitrogen beyond that in the Seed sown, assimilate free Nitrogen.

Year.	Plants. [†]	Number of seeds.	Period of growth.	Dry substance.		Nitrogen.										Per cent. in dry seed produce.
				Grammes.		Grammes.										
				In seed.	In plants produced.	In total plant.	In soil.	In pot.	In condensed water.	In total products.	Gain or loss.					
Graminaeae.																
1887.....	Wheat (1)	6	5	May 16—Oct. 3.....	0-3068†	1-413	4-81	-0-080	-0-072	traces	traces	-0-072	-0-008	80-0	0-51	
	Barley (2)	6	6	May 20—Aug. 24.....	0-2688	0-810	3-00	-0-066	-0-047	-0-024	-0-001	-0-072	+0-016	83-9	0-58	
	Barley (3)	6	6	May 20—Aug. 26.....	0-2688	0-925	3-43	-0-066	-0-045	-0-030	-0-007	-0-082	+0-026	80-4	0-56	
1888.....	Wheat (4)	8	8	April 27—Oct. 28.....	0-4035	1-740	4-31	-0-078	-0-066	-0-025	traces	-0-081	+0-008	71-8	0-32	
	Barley (5)	8	6	April 27—Aug. 18.....	0-3231	0-660	1-74	-0-087	-0-081	-0-027	traces	-0-068	+0-001	64-4	0-54	
	Oats (6)	8	8	April 27—July 13.....	0-2888	1-148	4-02	-0-068	-0-043	-0-011	-0-008	-0-046	-0-007	66-7	0-36	
1888, A.*	Wheat.....	8	7	June 11—Nov. 6.....	0-4031	1-060	2-83	-0-078	-0-041	-0-033	-0-004	-0-078	0-000	83-6	0-38	
	Barley.....	8	8	June 11—Nov. 6.....	0-3240	0-710	2-19	-0-087	-0-071	-0-037	-0-004	-0-078	0-000	83-6	0-38	
	Oats.....	8	7	June 11—Nov. 6.....	0-2879	0-690	2-40	-0-064	-0-038	-0-021	-0-004	-0-063	-0-001	89-4	0-55	
Leguminaeae.																
1887.....	Bean	3	3	May 16—July 5	1-4984	7-028	4-69	-0-096	-0-039	-0-146	-0-016	-0-091	-0-008	79-0	0-99	
	Bean	3	3	June 11—Aug. 23	1-4890	4-876	3-29	-0-076	-0-025	-0-016	-0-006	-0-067	+0-007	98-0	1-51	
1888.....	Pea	3	3	June 6—Aug. 24	0-6406	0-970	1-79	-0-188	-0-102	-0-066	-0-009	-0-167	-0-031	54-3	1-06	
Other Plants.																
1888.....	Buckwheat	24	13	Aug. 20—Oct. 28		0-450		-0-200	-0-070	-0-108	-0-004	-0-182	-0-018	35-0	1-56	

* These experiments were conducted in the apparatus of M. G. Yille.

† The numbers given in brackets refer to those of the figures of the respective plants given in Plate III.

‡ The percentage of dry matter in the seed was not determined in this case; it is therefore assumed to be the same as in the wheat used in 1888, from which it would certainly not differ at all materially.

nitrogen of the substance into the soluble state of ammonia. It would appear probable, therefore, that at least a part of the nitrogen found in the soil had never been in actual connexion with the plant; and it must be admitted, that a gain in the total products, without a gain in the plant itself, would, under the conditions in question, be unsatisfactory evidence of the assimilation of free nitrogen.

The results obtained with Graminaceæ in 1858, when some sources of error which the experience of the previous year had suggested had been eliminated, point, without exception, to the non-assimilation of free nitrogen. The process of cell formation has gone on; carbonic acid has been decomposed, and carbon and the elements of water assimilated; the nitrogenous compounds of the older cells have been withdrawn for the requirements of new ones; the roots, requiring the smallest amount of nitrogen, were extraordinarily developed; and all stages of growth have been passed, to the formation of glumes, pales, and awns, for seed, the other organic constituents increasing with one constant amount of combined nitrogen until its percentage in the vegetable matter was far below the usual amount. Throughout these phases, water saturated with free nitrogen has constantly been in contact with the contents of the cells and the cell-walls; the delicate membrane of the newly-forming cell, stunted in its development for want of assimilable nitrogen, has been saturated with water, itself saturated with free nitrogen; and such are the laws in accordance with which the absorption of gases, and the transmission of liquids through membranes take place, that the instant a part of the nitrogen became assimilated the equilibrium would be restored and the liquid resaturated, circumstances which would seem highly favourable to the assimilation of free nitrogen, provided it could take place at all.

In the experiments of 1857, several of the cereal plants developed a very large proportion of root, but fearing the double risk of losing the entire results in analysing the root and the rest of the plant separately, they were thoroughly mixed, and the mixture carefully divided, so as to provide confirmatory evidence if successful, or a duplicate in case of accident. The development was, however, so marked in the cereals of 1858, that the root was in several cases analysed separately. Table XIX shows the results obtained :—

TABLE XIX.

Plants.* (1858).	Dry matter.				Nitrogen.			
	In stems, &c.	In roots.	In total plant.	Per cent. of total in roots.	In stems, &c.	In roots.	In total plant.	Per cent. of total in roots.
	grm.	grm.	grm.		grm.	grm.	grm.	
Wheat (4).	0·890	0·850	1·740	48·85	0·0039	0·0017	0·0056	30·36
Barley (5).	0·400	0·160	0·560	28·57	0·0027	0·0004	0·0031	12·90
Oats (6) ...	0·798	0·350	1·148	30·49	0·0040	0·0002	0·0042	4·76

The large proportion of root, and its small proportion of nitrogen are equally remarkable. Whether the great development of root were due to the process of cell formation in it requiring less of the nitrogenous proto-plasmic compound, or to the withdrawal, by the fluid in which the roots floated, of the nitrogenous constituents from the old cells to form new proto-plasma for the more active cells, is a question of considerable interest in a physiological point of view. The fact that the roots gave off very few branches into the soil, but immediately on reaching the water in the pan exhibited such a remarkable development, is in favour of the inference that the water afforded the necessary conditions.

At any rate, this great development of the part of the plant requiring a minimum of nitrogen indicates an inability to assimilate free nitrogen within the range of growth possible when no combined nitrogen is provided beyond that in the seed sown; and it shows the great tenacity of growth, and activity of vital force, long after the organism began to require more available nitrogen—conditions apparently very favourable to the assimilation of free nitrogen; yet such has not been the result.

The Graminaceæ referred to in Table XVIII under the title "1858 A," which were grown in M. G. Ville's case, give results perfectly accordant with the rest; but being sown later, and their period of growth being shorter, there was neither so great a development of root nor so much total vegetable matter produced. Unfortunately, the barley of the series was lost by the giving way of the tube in combustion; so that, in its case, we can only give the amount of dry matter produced; but, comparing the

* The numbers given in brackets refer to those of the figures of the respective plants given in plate III.

results on this point with those in the other cases, there is no reason to believe that those in regard to the nitrogen would have been different.

It will be remembered that M. Boussingault and M. G. Ville obtained most discordant results in experimenting with Graminaceæ, and it will be seen that our own results, from nine experiments with such plants, go entirely to confirm those of M. Boussingault.

Leguminous Plants.

It has been shown in section 1 of this paper, that, under equal circumstances of soil and season, Leguminous crops yield two, three, or more times as much nitrogen per acre, as Graminaceous ones; that, nevertheless, the latter are very characteristically benefited by the direct use of ammoniacal manures, whilst the former are not so; and again, that a much larger Graminaceous crop is obtained after the growth and removal of a highly nitrogenous Leguminous one, than after another Graminaceous crop. Experiments such as those now under consideration, can obviously bear upon a few only of the circumstances which may be connected with the differences referred to. They do, however, bear upon the questions—(1) whether in the growth of the Graminaceæ, there is a decomposition of nitrogenous compounds and an evolution of free nitrogen? or, (2) whether the Leguminosæ may assimilate free nitrogen, and thus not only allow the resources of the soil to accumulate, but leave within it, in roots and other vegetable *débris*, an additional quantity of combined nitrogen?

The facts already considered do not indicate an evolution of free nitrogen from the nitrogenous compounds of Graminaceous plants during growth; and others, to which we shall presently refer, afford confirmatory evidence in the same direction.

With regard to the second point, as the growth of the Leguminous plants under the experimental conditions was generally not so healthy as that of the Graminaceæ, it may, perhaps, be maintained, that a negative result with them was not so conclusive as with the latter. In 1857, several experiments with beans were commenced, but they grew well in only one of the shades. These, however (especially one plant out of the two in the same pot), progressed remarkably well for 10 weeks, during which time the amount of dry matter, and consequently of carbon, increased

about five-fold; more than three-fourths of the nitrogen of the seed was appropriated, and the plants probably ceased to grow only when the remainder became so distributed in the soil as not to be available. The beans and peas of 1858 did not grow so satisfactorily as the beans of 1857 last referred to; yet the beans (of 1858) gave more than three times as much organic matter in the produce as was contained in the seed, and appropriated even a much larger proportion of the nitrogen of the seed than did those of 1857. The result with the peas was not so satisfactory, owing to the less healthy and more limited character of the growth. It may be added that none of these Leguminous plants arrived at the stage of flowering.

The result is, however, that active growth has taken place—that the process of cell formation, with the decomposition of carbonic acid and fixation of carbon, has gone forward with a deficient supply of combined nitrogen, and in the immediate presence of free nitrogen, both gaseous and dissolved—in fact, that the plants have been subjected to a considerable range of the conditions which appear, *à priori*, to be favourable to the assimilation of free nitrogen, yet none has been assimilated by these Leguminous plants any more than by the Gramineous ones.

It is a fact observed in agriculture, that manures rich in organic matter, frequently favour the growth of Leguminous crops; and without discussing the question whether they act as a source of carbonic acid merely, or of carbon-compounds of a more complicated character, attention may be called to the fact, that, in the experiments now under consideration, the vital forces were sufficiently energetic to perform the function of cell development and multiplication, from carbonic acid as the source of carbon, and yet they were incapable of effecting the appropriation of free nitrogen.

Buckwheat.

In the experiment with buckwheat, most of the seed sown came up, but about half of the plants lived only for a few days. The remainder went through all the stages of development to flowering, but the amount of growth was nevertheless very limited, the quantity of dry matter produced being less than that in the seed sown, and the nitrogen in the plants little more than one-third that in the seed. It will be seen further on, however, that on the addition of an amount of ammonia very small in its contents of

nitrogen compared with the seed, to plants in a precisely similar condition to those now under consideration, the increase of growth was extremely marked.

Reference to the column in Table XVIII giving the gain or loss of nitrogen, will show that, under the conditions of growth described, there was no gain of nitrogen by the buckwheat, but on the contrary a loss of nearly 2 milligrammes, doubtless due to the evolution of free nitrogen in the decomposition of some of the plants that died.

Various experimenters, from the time of De Saussure, have entertained the idea of the probability of the decomposition of nitrogenous compounds, and the evolution of free nitrogen, during the growth of plants. We have been engaged in following up the subject in a more direct manner, but attention may here be called to the incidental bearing upon it of the results above considered.

With no less force than they point to the non-assimilation of free nitrogen, do they show that there has been no evolution of free nitrogen from the nitrogenous compounds of the growing plant. At all events, from the constancy of the amount of combined nitrogen maintained in relation to that supplied, the assumption that an evolution has taken place, implies the still more improbable one, that there has been an exactly compensating assimilation. But, when supplied with an insufficient quantity of nitrogenous matter, the vegetable organism might not decompose any of that matter; and yet, with an excess of combined nitrogen, decomposition might take place. We shall, therefore, refer to this question again, in connexion with the results obtained when an extraneous supply of combined nitrogen was provided to the plants.

Experiments in which the Plants had a known supply of Combined Nitrogen beyond that contained in the Seed sown.

Although in the experiments already considered, the extent of growth was very limited, some of the cereals did indeed produce glumes and pales for seed; but none attained to the formation and ripening of the seeds themselves. It remains to consider, therefore, what may take place with more active and vigorous growth, and at a later stage of development.

We have suggested the improbability of an assimilation of free nitrogen taking place in the presence of an abundance of combined nitrogen; but if active, healthy, and vigorous growth are favourable to the assimilation of free nitrogen, and these conditions can only be attained by keeping within the reach of the plant an excess of combined nitrogen, we should have to conclude that free nitrogen could be taken up in the presence of, and in preference to, combined nitrogen; *a priori* conclusions on points involving vital phenomena are, however, obviously unsafe.

It is true, we have pointed out the improbability of an assimilation of free nitrogen in the presence of an excess of combined nitrogen, only so far as the vital process of the vegetable cell is concerned. But, the more active the growth, the greater must be the amount of newly-formed carbon-matter capable of consuming oxygen when the plant is removed from the influence of sunlight into the dark. That is, the more vigorous the growth in the sunlight, the greater may be the reducing power of the plant in the dark; and the greater this reducing power, the more nearly will the tendency of the forces approximate to an evolution of hydrogen, which, in the presence of free nitrogen dissolved in the fluids of the cell, may tend to form ammonia, to be, on the return of sunlight, appropriated by the plant. In connexion with this point it may be mentioned that in our investigation of the gases given off by plants under various circumstances, we have had an evolution of oxygen one day as a coincident of growth, and an evolution of hydrogen the next, as the result of decomposition.

The results of the experiments in which the plants were supplied with combined nitrogen beyond that in the seed sown, are given in Table XX, p. 81; and the figures 7—12, plate III, show the character and extent of development of six Gramineous plants with extraneous supply of combined nitrogen, corresponding to the six above them without such supply; and the vigour and extent of growth attained, may be taken as sufficient proof that the conditions of soil, atmosphere, temperature, &c., were consistent with active and healthy growth. As already explained, the combined nitrogen was supplied by means of dilute solutions of sulphate of ammonia.

It will be instructive to consider the results to which Table XX refers in regard—(1) to the actual gain or loss of nitrogen; (2) to the physiological evidence afforded during growth; (3) their indications as compared with the results obtained when there

TABLE XX.
Results of Experiments to determine whether Plants supplied with combined Nitrogen beyond that in the Seed sown, assimilate free Nitrogen.

Years.	Plants.	Number of seeds.	Period of growth.	Dry substance.			Nitrogen.											
				Grammes.		In produce per seed with ammonia, to that without it taken as 1.	Grammes.					In plants to 100 in seed and manure.	Per cent. in dry produce.	In produce per seed with ammonia, to that without it taken as 1.				
				In seed.	In plants produced.		In total plant.	In soil.	In pot.	In condensed water.	In ducta.				Gain or loss.			
																In seed.	In manure.	Total supplied.	In total plant.	In soil.	In pot.	In condensed water.	In ducta.	Gain or loss.
Graminaeae.																		
1857..	Wheat (7)	3	2	May 16—Oct. 2 ..	6.835	44.50	12.10	0.289	0.299	0.941	-0.133	-0.009	traces	0.333	+0.004	73.9	0.35	8.36
	Wheat	3	4	May 16—Sept. 30.	2.832	24.77	4.51	0.040	0.289	0.213	-0.102	0.016	0.001	0.331	+0.003	64.7	0.35	4.93
	Barley (8)	4	3	May 20—Oct. 8 ..	3.034	16.83	7.49	-0.037	0.289	0.226	-0.154	-0.013	0.003	0.328	+0.003	47.3	0.31	6.58
	Barley (9)	4	4	May 20—Sept. 24.	4.401	24.20	7.13	0.037	0.281	0.263	-0.145	-0.171	-0.021	0.337	+0.009	54.1	0.33	4.83
1858..	Wheat (10)	4	4	April 27—Oct. 26.	0.204	7.31	35.93	0.040	0.508	0.448	-0.398	-0.135	traces	0.536	-0.012	72.6	0.54	14.31
	Wheat (11)	4	2	April 27—Oct. 26.	0.158	6.47	29.81	0.028	0.468	0.496	-0.349	-0.113	0.002	0.164	-0.032	70.4	0.54	24.21
	Oats (12)	4	3	April 27—July 20.	0.145	1.204	2.80	0.032	0.280	0.312	-0.135	-0.040	0.001	0.216	-0.096	40.1	1.04	7.92
	Wheat	4	4	June 29—Dec. 9 ..	0.208	2.82	6.31	0.040	0.298	0.288	-0.181	-0.092	0.001	0.274	+0.008	67.5	0.47	7.79
1858, A*	Barley	4	3	June 29—Dec. 9 ..	0.163	2.86	11.19	0.029	0.283	0.217	-0.180	-0.081	0.001	0.243	-0.018	63.3	0.54	0.79
	Oats	4	2	June 29—Dec. 9 ..	0.144	1.28	6.49	0.032	0.238	0.260	-0.146	-0.051	0.001	0.198	-0.063	56.1	1.14	13.53
Leguminoes.																		
1858..	Pea	3	3	April 27—Aug. 24	0.539	1.01	1.87	0.187	0.400	0.227	-0.114	-0.086	0.011	0.211	-0.016	50.2	1.18	
	Clover			June 6—Oct. 26..	4.20			0.284	0.428	0.712	-0.313	-0.339	0.013	0.268	-0.047	44.0	0.76	
1858, A*	Bean	3	3	June 29—Dec. 9 ..	1.094	4.30	3.93	0.522	0.188	0.711	-0.401	-0.253	0.001	0.243	-0.066	56.4	0.93	
Other Plants.																		
1858.....	Buckwheat.	42	24	Aug. 20—Nov. 22.	0.640	1.97	2.22	0.200	0.108	0.308	-0.183	-0.101	0.008	0.222	-0.016	59.4	0.98	1.41

* These experiments were conducted in the apparatus of M. G. Ville.

† The numbers given in brackets refer to those of the figures of the respective plants given in Plate III.

‡ The percentage of dry matter in the seed was not determined in these two cases; it is therefore assumed to be the same as in the wheat used in 1848, from which it would certainly not differ at all materially.

was no other supply of combined nitrogen beyond that in the seed sown.

As in the experiments without, so also in those with a supply of combined nitrogen beyond that in the seed sown, there is generally a slight gain of nitrogen in those of 1857, but almost invariably a loss rather than a gain in those of 1858, when glazed stone-ware, instead of slate lute-vessels were employed; and considering the possible source of gain when slates were used, the whole of the results can be interpreted but in one way.

The slight loss of nitrogen in the experiments of 1858 is easily accounted for. The general character of growth of the peas, clover, and beans, under the experimental conditions, as already referred to, taken in connection with the evidence adduced as to the loss of nitrogen during the decomposition of nitrogenous organic matter, sufficiently explains the loss in their case. The loss in the cases of the wheat, barley, oats, and buckwheat (1858), would not be so easily explained, had not the combined nitrogen in the drainage-water remaining at the end of the experiment been determined separately; and the fact that a notable quantity of ammonia was found in the condensed water, only where there was a loss of combined nitrogen in the experiment, would lead to the inference, that both phenomena were due to the same cause.

The condensed water showing the amounts of combined nitrogen recorded in the table, was that collected during the last four weeks of growth; and during this period the high temperature, and the advanced stage of growth of the plants, were favourable to the evaporation of ammoniacal water. Owing to the comparatively low temperature of the shade, a large proportion of the vapour would condense on its interior, and finally be collected in the bottle O; but a certain quantity of that present in the atmosphere of the apparatus, during the passage of the air through it, would be borne forward into the sulphuric acid in the bulb-apparatus M, and thus occasion a loss of combined nitrogen. The reason of the greater loss in both the experiments with oats than in those of the other cereals, is not perfectly obvious; but in connection with this point it may be mentioned that, in one case more particularly, they ripened at a much warmer period of the season, and becoming much drier in stem and leaf, might be more liable to evolve ammonia.

It is, however, not enough to consider the actual gain or loss of nitrogen merely, but it is desirable to take into account the total

quantity of nitrogen at the disposal of the plants, and also the amount and character of growth, under the different conditions, or, in other words, the physiological evidence.

We have already called attention to the fact of the very great increase of growth when a supply of combined nitrogen, extraneous to that of the seed sown, was provided. This is strikingly illustrated by the figures in the columns of Table XX, which show the amounts respectively, of dry substance and of nitrogen, in the final produce per seed with ammonia to that without it taken as 1; but the indications manifested from the earliest periods of growth require to be briefly noticed.

When they first came up, all the plants looked green and vigorous, indicating the presence of all conditions essential to healthy growth; and there can be little doubt that, at that time, they were supplied with an excess of combined nitrogen in relation to their immediate wants. After some days, varying with the nature of the plants, they began to assume a lighter green or pale yellow tint, indicative of a want of combined nitrogen. It has been already pointed out how favourable, probably, would be the condition for the assimilation of free nitrogen, when the plant was passing from the state in which it had an excess to that in which it had a deficiency of combined nitrogen for the demands of growth. The vigorous development of the plants grown under the same conditions as the other experimental plants, but in garden soil (fig. 13, plate III.), indicates that the conditions of atmosphere, &c., provided, were not at fault. If a supply of combined nitrogen alone be deficient when the plants show the declining vigour above described, they will, on its addition, resume their healthy green colour. Or, if combined nitrogen be added before the plants decline, it will prevent them assuming the pale green or yellow colour. Both these expedients have been adopted; and so far as the cereals, buckwheat, and clover are concerned, each has yielded a result indicating that combined nitrogen alone was needed for healthy growth.

The plants to which ammonia was given in 1857, were allowed to suffer more before they received it, than those of 1858; yet in thirty-six hours after its addition to the soil, in amount not exceeding 1.5 milligramme of nitrogen to each plant, they began manifestly to improve, and in two or three days the effect was quite marked; but at the termination of periods varying from nine to eighteen days, they seemed to have consumed all that had

not become inaccessible in the soil, and began to show the **same** indications of defective supply as before. A new increment of combined nitrogen (excepting when in one or two instances it **was** added too late) caused a new increment of growth, greener colour, and a more vigorous appearance generally, to be soon followed by the recurrence of the pale colour, and so on. At each recurrence of these conditions, the plants must have passed, at a more advanced stage of growth than before, from the point of having an excess to that of having a deficiency of combined nitrogen.

A considerable range of conditions of growth was thus provided. Just after each addition, the plants must have been supplied with an excess of nitrogen in an available form, as was evinced in the formation of new shoots from the base or the nodes of the plants. But these new shoots, at first growing vigorously, soon suffered for want of a new supply; and in passing to this point, the newly-formed and vigorously-growing portion of the vegetable matter, would be in the condition assumed to be the most favourable to the assimilation of free nitrogen. This cycle of conditions, repeated several times during the growth of the same plant, and the experiment similarly conducted with a number of pots of plants of different kinds, with like results in all cases, afforded a wide range of circumstances assumed to be favourable to the assimilation of free nitrogen, which, however, has not taken place.

Table XX shows, that there remained in the soil, at the termination of the experiment, a greater or less amount of the combined nitrogen artificially supplied, yet the physiological evidence sufficiently showed the effect of each new addition; nor is it difficult to imagine that a few milligrammes of ammonia, intermingled with 1,500 or 1,600 grammes of soil (and pot), might become so distributed and absorbed, that a considerable proportion should remain inaccessible to the plant.

The Gramineaceous plants of 1858 were supplied with combined nitrogen at an earlier period of growth than those of 1857, and were not allowed to show such marked signs of deficiency before receiving fresh supplies.

Attention should be called, in passing, to the remarkable character of growth exhibited in some of the experiments.

Shortly after the addition of ammonia to the Gramineaceæ for the first time, the plants began to throw out new shoots from the base of the principal stem, as if they had first developed a stem commensurate with the limited amount of combined nitrogen con-

tained in the seed, and then, with the new supplies, been obliged to find vent for their activity in new directions. Some of the new shoots came forth close to the surface of the soil, some at the first, and some at the second nodes, as the drawings of the plants, given in plate III, will show.

Another remarkable feature was the formation of roots at the second and third nodes above the ground, in the case of most of the Graminaceæ to which ammonia-salt was added. These roots came out around the node, and extended downwards, several reaching the soil from heights varying from $\frac{1}{2}$ to $1\frac{1}{2}$, or even 2 inches, and penetrating it to the bottom of the pot. The most marked instance was that of the barley, fig. 11, plate III, given in more detail with special reference to these points, in fig. 16, plate III. As the figures show, roots and new stems came from the same node, making the latter a new axis of growth, like the seed in the first instance. The original stems, below these nodes, did not increase much in size with the addition of ammonia, but the stems above the nodes became much larger than the portions below them, as did those of the new shoots.

Finally, in regard to the Graminaceæ: so long as an additional supply of combined nitrogen increased growth, so long must the physiological conditions have required available nitrogen, and therefore have been more or less favourable to the assimilation of free nitrogen if this were possible; but no such assimilation took place.

With regard to the other plants little more need be said than to direct attention to the columns of gain or loss of nitrogen. As already observed, the growth of the Leguminosæ was by no means so satisfactory as that of the Graminaceæ; and hence, the results relating to them apply to a more limited range of conditions of growth, and are, therefore, less conclusive against the possibility of the assimilation of free nitrogen in their case; though, so far as they go, they, as well as those with the buckwheat, tend to confirm those with the cereals. It should be remembered, too, that M. Boussingault experimented with a great many Leguminous plants, and generally succeeded in getting much more healthy growth than we were able to do, but in no case did he find any such gain of nitrogen as to lead to the conclusion that free nitrogen had been assimilated. We shall, ourselves, have additional evidence to bring forward on this subject on a future occasion.

In regard to the single experiment with clover, the results of which are given in Table XX, it may be mentioned that we failed

to get any growth in the experiment attempted without the addition of ammonia, and obtained comparatively little with it. Beans and peas also proved so sensitive under the conditions of experiment, and were so much less characteristically benefited by the supply of ammonia-salts, that it was obvious they suffered from other causes than a want of combined nitrogen. In subsequent experiments, however, nitrates have been found to be much more beneficial than ammonia-salts; as, indeed, they are when applied to Leguminous crops grown in the field.

It has already been pointed out that the beans grown in 1857 without extraneous supply of combined nitrogen, appropriated nearly four-fifths, and those grown in the same way in 1858 a larger proportion still, of the nitrogen of the seed sown. In contrast with these results, it may be mentioned that, in the experiment with beans, "1858 A" (see Table XX), there were 0.0523 gramme of nitrogen in the seed sown, and 0.0188 gramme supplied as ammonia-salt, making together 0.0711 gramme, of which the plants appropriated only 0.0401 gramme, or about one-fifth less than was supplied in the seeds alone; yet, it was in this experiment with Leguminous plants, that the addition of ammonia-salt produced the most obvious effects on the growth.

From a review of the whole of the results of the direct experiments on the question of assimilation, it appears that the Gramineaceous plants grew the most healthily, and provided a wide range of conditions for the assimilation of free nitrogen; that the Leguminous plants were less healthy, and therefore provided a more limited range of conditions for assimilation; and that the growth of other plants was also less satisfactory than that of Gramineaceous ones. In all, the growth was more or less increased by the supply of combined nitrogen beyond that contained in the seed. The effect was the most marked with the Gramineaceous plants, their increase of dry vegetable substance due to the extraneous supply of combined nitrogen being 8, 12, and even nearly 30-fold, according to the amount provided. Yet, with 19 experiments with Gramineaceous plants, 6 with Leguminous ones, and some with plants of other descriptions, with such great variation in the amount and character of growth, and in the amount of combined nitrogen involved in the experiment in the several cases, in no instance have the results been such as to lead to the conclusion that there was an assimilation of free nitrogen.

The results of the whole enquiry may be briefly enumerated as follows :—

The yield of nitrogen in the vegetation over a given area of land, within a given time, especially in the case of Leguminous crops, is not satisfactorily explained by reference to the hitherto quantitatively determined periodical supplies of combined nitrogen.

Numerous experiments have been made by M. Boussingault, from which he concludes that free or uncombined nitrogen is not a direct source of the nitrogen of vegetation. M. G. Ville, on the other hand, concludes, from his results, that free nitrogen may be a source of a considerable proportion of the nitrogen of growing plants. The views, or explanations, of other experimenters, on this disputed point, are various and inconclusive.

It was found that the conditions of growth adopted in our own experiments on the question of the assimilation of free nitrogen, were consistent with the healthy development of various Gramineous plants, but less so for that of the Leguminous plants experimented upon.

From the results of various investigations, as well as from other considerations, we think it may be concluded that, under the circumstances of our experiments, there would not be any supply to the plants of an unaccounted quantity of combined nitrogen, due either to the formation of oxygen-compounds of it under the influence of ozone, or nascent oxygen, or to that of ammonia under the influence of nascent hydrogen.

We have found that free nitrogen is given off in the decomposition of nitrogenous organic matter under certain circumstances. But, considering the circumstances of such evolution, and those to which the nitrogenous organic matter necessarily involved in experiments on the question of assimilation of free nitrogen is subjected, it may, we think, be concluded that there would be no loss of combined nitrogen from this cause in such experiments, excepting in certain cases when it might be pre-supposed.

Our experimental evidence, so far as it goes, does not favour the supposition that there would be any loss of combined nitrogen in the experiments on assimilation, due to the evolution of free nitrogen from the nitrogenous constituents of the plants during growth.

In numerous experiments with Gramineous plants, grown both with and without a supply of combined nitrogen beyond that contained in the seed sown, in which there was great variation in the

amount of combined nitrogen involved, and a wide range in the conditions, character, and amount of growth, we have in no case found any evidence of an assimilation of free or uncombined nitrogen.

In our experiments with Leguminous plants, the growth was less satisfactory, and the range of conditions possibly favourable for the assimilation of free nitrogen was, therefore, more limited. But the results recorded with these plants, so far as they go, do not indicate any assimilation of free nitrogen. Since, however, in practice, Leguminous crops assimilate, from some source, so very much more nitrogen than Graminaceous ones, under ostensibly equal circumstances of supply of combined nitrogen, it is desirable that the evidence of further experiments with these plants, under conditions of more healthy growth, should be obtained.

Results obtained with some other plants are in the same sense as those obtained with Graminaceæ and Leguminosæ, in regard to the question of the assimilation of free nitrogen.

In view of the evidence of the non-assimilation of free nitrogen by plants under the wide range of circumstances provided in the experiments, it is desirable that the several actual or possible sources of *combined* nitrogen to plants should be more fully investigated, both qualitatively and quantitatively.

If it be established that the processes of vegetation do not bring free nitrogen into combination, it still remains not very obvious to what actions a large proportion of the existing combined nitrogen may be attributed.

Fig. 1.

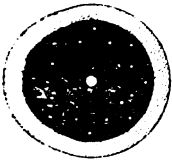


Fig. 2.

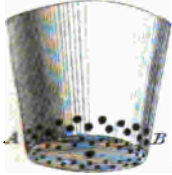


Fig. 3.

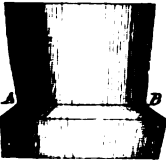


Fig. 7.



Fig. 4.

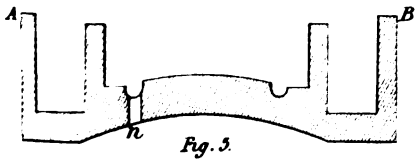
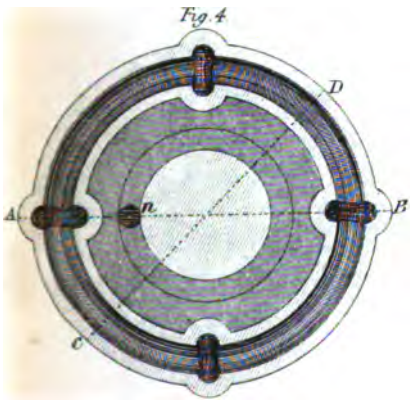
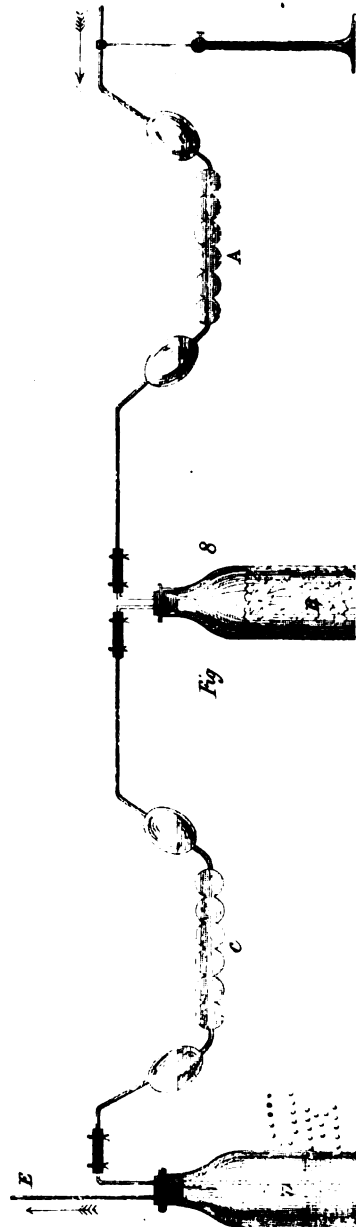


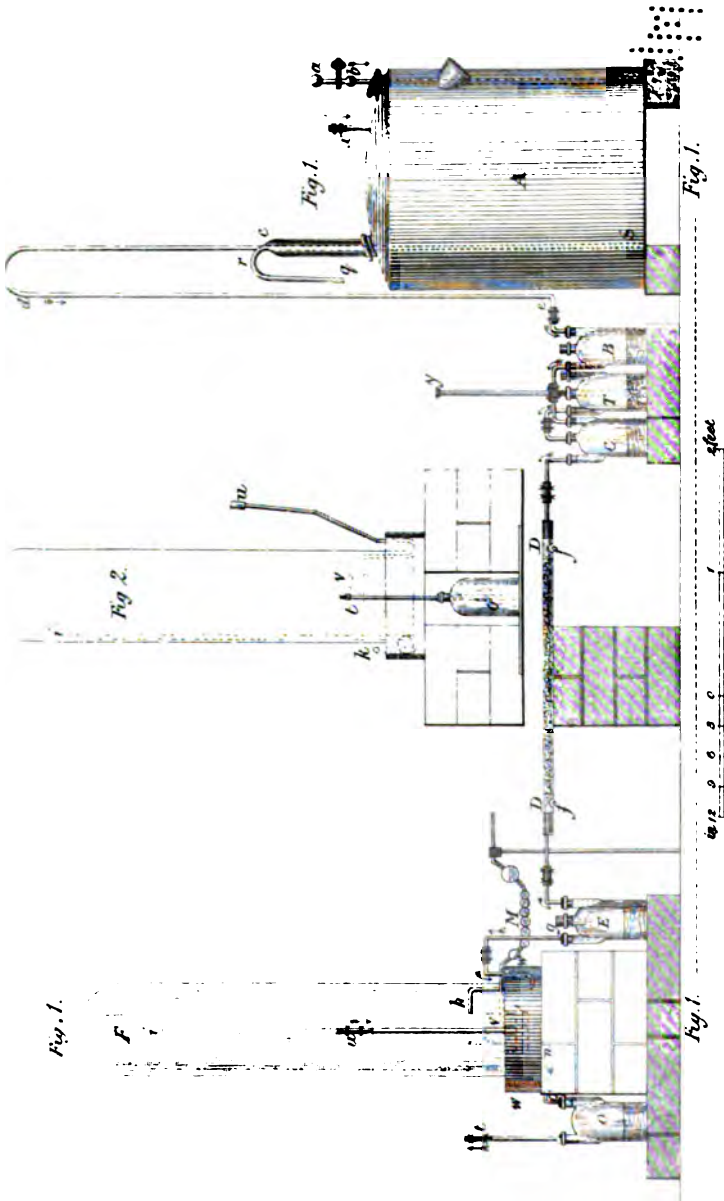
Fig. 5.



Fig. 6.



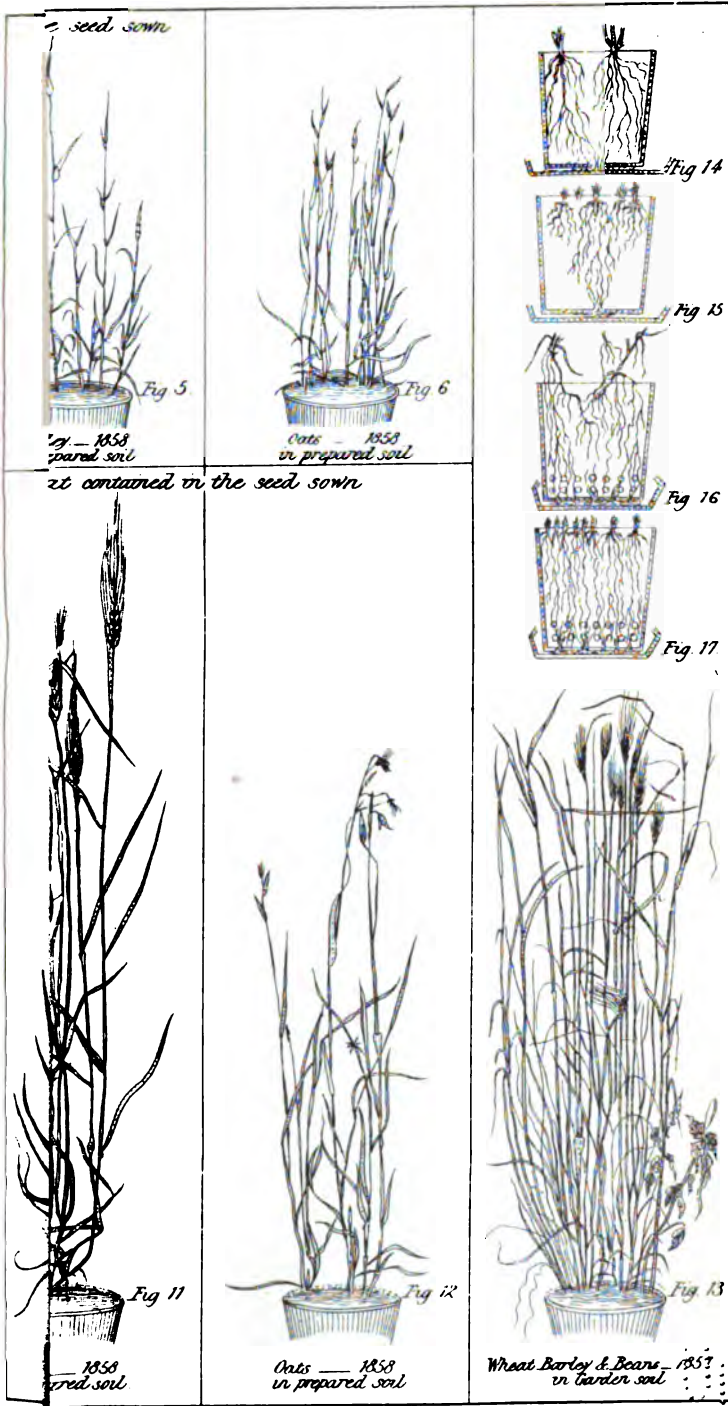
20



Handwritten notes and markings along the right margin, including a large 'X' and some illegible text.

Handwritten notes in the upper left quadrant, consisting of several lines of text.

Vertical line of text or markings on the far left edge of the page.



LIEBIG AND THE "MINERAL THEORY."

[Note, extracted from a Paper, by Messrs. LAWES and GILBERT,
Journal of the Royal Agricultural Society of England, Vol. xxiv.,
Part 2, 1863.]

LIEBIG AND THE "MINERAL THEORY."

THE terms "mineral" and "inorganic," as applied to the constituents of manures or crops, are, for convenience, employed throughout this paper to designate the incombustible or "ash constituents," they having been generally employed in this restricted sense by Liebig and most other writers on agricultural chemistry during the last twenty years or more. Yet, in his recent work (*Einführung in die Naturgesetze des Feldbaues*, p. 32 *et seq.*) Baron Liebig repudiates and ridicules such a classification as unscientific, claims ammonia and its salts as mineral manures, and accuses Mr. Lawes of setting up, in opposition to his own, a theory according to which mineral or inorganic manures should contain only incombustible or ash constituents. To support this allegation, he gives, in a separate paragraph, and in italics (*Sperrschrift*), the following sentence as a quotation from Mr. Lawes's paper on 'Agricultural Chemistry,' vol. viii. p. 240, of this Journal:—

"Manures are generally divided into two classes, organic and inorganic: organic manures are those which are capable of yielding to the plant, by decomposition or otherwise, carbon, hydrogen, and nitrogen. Inorganic manures are those substances which contain the mineral ingredients of which the ash of plants is found to consist."—[Translation.]

But the following is the passage as it really stands at the page referred to by Baron Liebig, and the portions given in capitals are those which are omitted by Baron Liebig in his professed quotation:—

"I NOW COME TO THE ACTION OF MANURES, WHICH ARE GENERALLY DIVIDED INTO TWO CLASSES—*ORGANIC* AND *INORGANIC*. ALTHOUGH THIS DISTINCTION IS BY NO MEANS SATISFACTORY, I SHALL ADOPT IT AS BEING GENERALLY UNDERSTOOD. Organic manures are those which are capable of yielding to the plant, by decomposition or otherwise, ORGANIC MATTER—carbon, hydrogen, oxygen, and nitrogen—CONSTITUENTS WHICH UNCULTIVATED PLANTS DERIVE ORIGINALLY FROM THE ATMOSPHERE. Inorganic manures are those substances which contain the mineral ingredients, of which the ash of plants is found to consist."

Here, then, in this which was Mr. Lawes's first paper, the classification which Baron Liebig accuses him of originating is only adopted as being already at that time "generally understood," and with a distinct protest that it is "by no means satisfactory." Yet, in order to fix the origination of the distinction upon Mr. Lawes, Baron Liebig joins together disconnected parts of a passage, and gives them, in a separate paragraph, in italics (*Sperrschrift*), and between unbroken inverted commas, omitting (besides less material portions) an entire sentence which distinctly disproves the truth of the allegation in support of which the professed quotation is brought forward! Having thus moulded Mr. Lawes's sentence to suit the requirements of his argument, he goes on to say:—

"From this doctrine of the practical man it necessarily followed that a mineral manure must be one which contained *only* the ash constituents of vegetable products, and from the composition of which ammonia-salts, as belonging to organic manures, are excluded. To be sure, in every chemical manual ammonia and its salts are treated of among inorganic substances, since they are objects of chemical manufacture, whilst organic matters cannot be produced by man; and this fact might well have led to the suspicion that ammonia was not necessarily excluded from an inorganic manure. The agricultural chemistry of the practical man was evidently a peculiar chemistry, which had no connexion with ordinary chemistry, and thus *his* theory might well find some justification, but according to *my* theory I obviously took another point of view. Mr. Lawes, indeed, mentions in his paper (p. 21), that my manures smelt of ammonia, and hence contained an ammonia-salt; but he implied that this might be a little artifice, in order to give to my manures an efficacy which, according to his interpretation of my theory, they should not possess."—[Translation.]

The following quotations, taken from several of Baron Liebig's works, will show whether he has not been accustomed to use the terms "mineral" and "inorganic" to designate the incombustible or ash constituents, and to distinguish

these from "ammonia," "ammoniacal salts," "atmospheric constituents," &c. The italicising is our own:—

"The *mineral* constituents act, as is shown by the produce of the unmanured land, without any artificial supply of *ammonia*."

"The *ammonia* increases the produce only if the *mineral* constituents be present in the soil in due quantity, and in an available form.

"*Ammonia* is without effect if the *mineral* constituents are wanting. Consequently, the action of *ammonia* is limited to the acceleration of the action of the *mineral* constituents in a given time."—*Principles*, pp. 86-7 (1855).

"..... the other is the action of *sulphate of ammonia* as a solvent for certain important *mineral* constituents of the soil."—*Ib.*, p. 99 (1855).

"*Ammonia*, when used as a manure alone, and when there is a want of *mineral* constituents in the soil, is like the spirits which the labourer takes in order to increase his available labour, power, or imagination; and, like that stimulant, its action, in this case, is followed by a corresponding exhaustion."—*Ib.*, p. 106 (1855).

"Hence it is quite certain that in our fields the amount of nitrogen in the crops is not at all in proportion to the quantity supplied in the manure, and that the soil cannot be exhausted by the exportation of products containing *nitrogen* (unless these products contain at the same time a large amount of *mineral* ingredients), because the *nitrogen* of vegetation is furnished by the atmosphere, and not by the soil. Hence also we cannot augment the fertility of our fields, or their powers of production, by supplying them with manures rich in *nitrogen*, or with *ammonia salts* alone. The crops on a field diminish or increase in exact proportion to the diminution or increase of the *mineral substances* conveyed to it in manure."—4th Edition, p. 210 (1847?).

"But, at the same time, it is of great importance for agriculture to know with certainty that the supply of *ammonia* is unnecessary for most of our cultivated plants, and that it may be even superfluous, if only the soil contain a sufficient supply of the *mineral* food of plants, when the *ammonia* required for their development will be furnished by the atmosphere."—4th Edition, p. 212 (213).

"A fertile soil must contain in sufficient quantity, and in a form adapted for assimilation, all the *inorganic* materials indispensable for the growth of plants.

"A field artificially prepared for culture contains a certain amount of these *ingredients*, and also of *ammoniacal salts* and decaying vegetable matter."—4th Edition, p. 169.

"The meaning of these sentences in my work is this: 'that *ammoniacal salts* alone' have no effect; that, in order to be efficacious, they must be accompanied by the *mineral constituents*, and that the effect is then proportional to the supply—not of *ammonia*, but of the *mineral substances*."—*Principles*, p. 55 (1855).

"These two paragraphs are altogether irreconcilable; for if Mr. Lawes admit that the *mineral* constituents are indispensable to plants, how can he maintain that these very *mineral* constituents are replaceable by *ammonia*, that is to say, that by means of *ammonia* we can altogether dispense with them?"—*Principles*, p. 89 (1855).

"It has been mentioned in the preceding part of the chapter, that animal excrements may be replaced in agriculture, by other materials containing their constituents. Now, as the principal action of the former depends upon their amount of *mineral* food so necessary for the growth of cultivated plants, it follows, that we might manure with the *mineral* food of wild plants, or, in other words, WITH THEIR ASHES [the capitals are Baron Liebig's own]; for, these plants are governed by the same laws, in their nutrition and growth, as cultivated plants themselves."—3rd Edition, p. 183 (1843).

"But the weight or amount of the crops is in proportion to the quantity of food of both kinds, *atmospheric* and *mineral*, which is present in the soil, or conveyed to it in the same time. By manuring with *ammoniacal salts* a soil rich in available *mineral* constituents, the crops are augmented in the same way as they would have been if we had increased the proportion of *ammonia* in the air."—*Principles*, p. 77-8 (1855).

These sentences will be sufficient to show whether or not Liebig is justified in now attempting to fall back, in agricultural discussions, upon the more strictly scientific meaning of the terms "*mineral*" and "*inorganic*," so as to include within them "*ammonia*," "*ammoniacal salts*," "*atmospheric constituents*," &c., and thus to give a new definition to his *mineral* theory, or rather substitute at this date for his own theory, which has proved to be erroneous, another not his own.



FURTHER REPORT
OF
EXPERIMENTS WITH DIFFERENT MANURES
ON
PERMANENT MEADOW LAND.

BY
J. B. LAWES, F.R.S., F.C.S., & J. H. GILBERT, PH.D., F.R.S., F.C.S.

LONDON:
PRINTED BY W. CLOWES AND SONS, STAMFORD STREET,
AND CHANCING CROSS.
1863.

FROM THE
JOURNAL OF THE ROYAL AGRICULTURAL SOCIETY OF ENGLAND,
VOL. XXIV, PART II.

EXPERIMENTS WITH DIFFERENT MANURES.

THE object of the present Report is to give an account of the produce of hay per acre, the chemical composition of the hay, and the amount of certain constituents removed from the land, in the fourth, fifth, sixth, and seventh seasons of experiments on the application of different descriptions of manure, each applied (with some few exceptions or modifications) year after year on the same of a series of plots of permanent meadow land. The results obtained on the above points in the first, second, and third years, and on the variation in the description of plants developed in the third year, were given in vols. xix. and xx. of the R. Agr. Journal; and in the last Number (vol. xxiv., part 1) a detailed account of the description of plants developed by the different manures in the last or seventh season (1862), was given.

It is proposed to give the numerical results obtained during the last four years in regard to the points in question in some detail, but to comment on them much more briefly than it was found desirable to do when treating of the subject for the first time, in the Report above alluded to, to which we would refer the reader for a more detailed consideration of some of the points now discussed more briefly. We shall, however, give in the Tables a condensed summary of the results obtained over the whole seven years of the experiments, side by side with those of the later years, and in the course of our comments frequently compare the earlier and the later results.

The following is a detailed statement of the manuring of each plot; and, unless otherwise stated, it has been the same every year since the commencement of the experiments in 1856. The quantities per acre are given.

Plot 1. Unmanured.

Plot 2. Unmanured (duplicate plot at the further end of the series).

Plot 3a. Superphosphate of lime; composed of 200 lbs. of bone ash, and 150 lbs. sulphuric acid of sp. gr. 1.7. 4th season (commencing in 1859); sawdust alone the three previous years.

Plot 3b. Superphosphate of lime; and 400 lbs. ammonia-salts (equal parts sulphate and muriate of commerce, supplying about 82 lbs. nitrogen per acre). 4th season (commencing in 1859); the three previous seasons sawdust alone.

Plot 4. 400 lbs. ammonia-salts.

- Plot 5. 400 lbs. ammonia-salts, and 2000 lbs. sawdust.
- Plot 6. 275 lbs. nitrate of soda of commerce (containing about 41 lbs. nitrogen). 5th season (commencing 1858).
- Plot 7. 550 lbs. nitrate of soda (containing about 82 lbs. nitrogen). 5th season (commencing in 1858).
- Plot 8. Mixed mineral manure, composed of—
 300 lbs. sulphate of potass.
 200 lbs. sulphate of soda.
 100 lbs. sulphate of magnesia.
 Superphosphate of lime, as above.
- Plot 9. Mixed mineral manure, and 2000 lbs. sawdust. (The mixed mineral manure as plot 8 to 1861 inclusive, and in 1862 the sulphate of potass excluded, and the amount of sulphate of soda raised to 500 lbs.).
- Plot 10. Mixed mineral manure, as plot 8, and 400 lbs. ammonia-salts.
- Plot 11. Mixed mineral manure, as plot 9, 400 lbs. ammonia-salts, and 2000 lbs. sawdust.
- Plot 12. Mixed mineral manure, as plot 8, 400 lbs. ammonia-salts, and 2000 lbs. cut wheat-straw.
- Plot 13a. Mixed mineral manure, as plot 8, and 800 lbs. ammonia-salts, equal about 164 lbs. nitrogen (only 400 lbs. ammonia-salts in 1859, 1860, and 1861).
- Plot 13b. Mixed mineral manure, as plot 13a, to 1861 inclusive; the same, with 200 lbs. silicate of soda and 200 lbs. silicate of lime in addition, in 1862, and 800 lbs. ammonia-salts (only 400 lbs. ammonia-salts in 1859, 1860, and 1861).
- Plot 14. Mixed mineral manure, as plot 8, and 275 lbs. nitrate of soda. 5th season (commencing in 1858).
- Plot 15. Mixed mineral manure, as plot 8, and 550 lbs. nitrate of soda. 5th season (commencing in 1858).
- Plot 16. 14 tons farmyard manure.
- Plot 17. 14 tons farmyard manure, and 200 lbs. ammonia salts.

The first crop each year has always been mown for hay, and the after-grass eaten off by sheep, once or twice as might be required, a certain number, according to the amount of grass, being folded on each plot, and the number of days occupied in its consumption noted.

Produce of Hay per acre (First Crop).

In Table I. (p. 29) are given the quantities of hay obtained per acre (first crop) from each plot in each of the four years, 1859, 1860, 1861, and 1862; also the average annual produce, and average annual increase by manure, over the four and over the

whole seven years of the experiments (1856-1862 inclusive). It is, of course, a matter of much interest to consider, not only the actual amounts of produce, or of increase, obtained from each of the differently manured plots, but also, whether the amounts increase or diminish year by year as the experiments proceed.

The duplicate unmanured plot, which was somewhat shaded from the afternoon sun, gave each year rather more produce than the other. Taking the mean of the two, the average annual yield of hay per acre, without manure, was, over the whole seven years, nearly 25½ cwts., and over the last four years rather more than 26 cwts., showing that there is as yet no indication of progressive deterioration where only the natural produce of the soil and season is taken from the land. Nor is there as yet evidence of material falling off in gross produce in any case where artificial mineral manures were employed, notwithstanding that none of those used supplied every mineral or inorganic * constituent taken off in the increased crop. The details

* The terms "mineral" or "inorganic," as applied to the constituents of manures or crops, are, for convenience, employed throughout this paper to designate the incombustible or "ash constituents," they having been generally employed in this restricted sense by Liebig and most other writers on agricultural chemistry during the last twenty years or more. Yet, in his recent work (*Einleitung in die Naturgesetze des Feldbaues*, p. 32 *et seq.*) Baron Liebig repudiates and ridicules such a classification as unscientific, claims ammonia and its salts as mineral manures, and accuses Mr. Lawes of setting up, in opposition to his own, a theory according to which mineral or inorganic manures should contain only incombustible or ash constituents. To support this allegation, he gives, in a separate paragraph, and in italics (*Sperrschrift*), the following sentence as a quotation from Mr. Lawes's paper on 'Agricultural Chemistry,' vol. viii. p. 240, of this Journal:—

"Manures are generally divided into two classes, organic and inorganic: organic manures are those which are capable of yielding to the plant, by decomposition or otherwise, carbon, hydrogen, and nitrogen. Inorganic manures are those substances which contain the mineral ingredients of which the ash of plants is found to consist."—[Translation.]

But the following is the passage as it really stands at the page referred to by Baron Liebig, and the portions given in capitals are those which are omitted by Baron Liebig in his professed quotation:—

"I NOW COME TO THE ACTION OF manures, WHICH are generally divided into two classes—*organic* and *inorganic*. ALTHOUGH THIS DISTINCTION IS BY NO MEANS SATISFACTORY, I SHALL ADOPT IT AS BEING GENERALLY UNDERSTOOD. Organic manures are those which are capable of yielding to the plant, by decomposition or otherwise, ORGANIC MATTER—carbon, hydrogen, oxygen, and nitrogen—CONSTITUENTS WHICH UNCULTIVATED PLANTS DERIVE ORIGINALLY FROM THE ATMOSPHERE. Inorganic manures are those substances which contain the mineral ingredients, of which the ash of plants is found to consist."

Here, then, in this which was Mr. Lawes's first paper, the classification which Baron Liebig accuses him of originating is only adopted as being already at that time "generally understood," and with a distinct protest that it is "by no means satisfactory." Yet, in order to fix the origination of the distinction upon Mr. Lawes, Baron Liebig joins together disconnected parts of a passage, and gives them, in a separate paragraph, in italics (*Sperrschrift*), and between unbroken inverted commas, omitting (besides less material portions) an entire sentence

given in our paper in the last Number of the R. Agr. Journal do show, however, that the description of plants developed has, in most cases, been much changed, and in some deteriorated, under

which distinctly disproves the truth of the allegation in support of which the professed quotation is brought forward! Having thus moulded Mr. Lawes's sentence to suit the requirements of his argument, he goes on to say:—

"From this doctrine of the practical man it necessarily followed that a mineral manure must be one which contained *only* the ash-constituents of vegetable products, and from the composition of which ammonia-salts, as belonging to organic manures, are excluded. To be sure, in every chemical manual ammonia and its salts are treated of among inorganic substances, since they are objects of chemical manufacture, whilst organic matters cannot be produced by man; and this fact might well have led to the suspicion that ammonia was not necessarily excluded from an inorganic manure. The agricultural chemistry of the practical man was evidently a peculiar chemistry, which had no connexion with ordinary chemistry, and thus *his* theory might well find some justification, but according to *my* theory I obviously took another point of view. Mr. Lawes, indeed, mentions in his paper (p. 21), that my manures smelt of ammonia, and hence contained an ammonia-salt; but he implied that this might be a little artifice, in order to give to my manures an efficacy which, according to his interpretation of my theory, they should not possess."—[Translation.]

The following quotations, taken from several of Baron Liebig's works, will show whether he has not been accustomed to use the terms "mineral" or "inorganic" to designate the incombustible or ash-constituents, and to distinguish these from "ammonia," "ammoniacal salts," "atmospheric constituents," &c. The italicising is our own:—

"The *mineral* constituents act, as is shown by the produce of the unmanured land, without any artificial supply of *ammonia*."

"The *ammonia* increases the produce only if the *mineral* constituents be present in the soil in due quantity, and in an available form.

"*Ammonia* is without effect if the *mineral* constituents are wanting. Consequently, the action of *ammonia* is limited to the acceleration of the action of the *mineral* constituents in a given time."—*Principles*, pp. 86-7 (1855).

"..... the other is the action of *sulphate of ammonia* as a solvent for certain important *mineral* constituents of the soil."—*Ib.*, p. 99 (1855).

"*Ammonia*, when used as a manure alone, and when there is a want of *mineral* constituents in the soil, is like the spirits which the labourer takes in order to increase his available labour, power, or imagination; and, like that stimulant, its action, in this case, is followed by a corresponding exhaustion."—*Ib.*, p. 106 (1855).

"Hence it is quite certain that in our fields the amount of nitrogen in the crops is not at all in proportion to the quantity supplied in the manure, and that the soil cannot be exhausted by the exportation of products containing *nitrogen* (unless these products contain at the same time a large amount of *mineral* ingredients), because the *nitrogen* of vegetation is furnished by the atmosphere, and not by the soil. Hence also we cannot augment the fertility of our fields, or their powers of production, by supplying them with manures rich in *nitrogen*, or with *ammonia* salts alone. The crops on a field diminish or increase in exact proportion to the diminution or increase of the *mineral substances* conveyed to it in manure."—4th Edition, p. 210 (1847?).

"But, at the same time, it is of great importance for agriculture to know with certainty that the supply of *ammonia* is unnecessary for most of our cultivated plants, and that it may be even superfluous, if only the soil contain a sufficient supply of the *mineral* food of plants, when the *ammonia* required for their development will be furnished by the atmosphere."—4th Edition, p. 212 (213).

"A fertile soil must contain in sufficient quantity, and in a form adapted for assimilation, all the *inorganic* materials indispensable for the growth of plants.

"A field artificially prepared for culture contains a certain amount of *these ingredients*, and also of *ammoniacal salts* and decaying vegetable matter."—4th Edition, p. 169.

"The meaning of these sentences in my work is this: 'that *ammoniacal salts*

the influence of the different manures; and those given further on relating to the chemical composition of the hay, and to the amount of constituents removed from the land, will lead to the conclusion that some of the manures have so forced the crop as materially to reduce the available store within the soil of some constituents which the manures themselves did not supply. On the other hand, even with 14 tons of farmyard manure per acre per annum, doubtless supplying annually much more of every mineral constituent than would be removed in the crop, the rate of increase is very little higher during the last four than during the whole seven years of the experiments.

With ammonia-salts alone (Plot 4) there has been an average increase over the seven years of about 8 cwts., and with ammonia salts and sawdust (Plot 5) of about 9 cwts. of hay per acre per annum; but over the last four years, of only about $5\frac{1}{2}$ cwts. with ammonia salts alone, and about $7\frac{1}{2}$ cwts. with the sawdust in addition. It is obvious, therefore, that, when ammonia salts were used year after year without mineral manure, there was an undue exhaustion of the mineral constituents of the soil. That this was so is confirmed, not only by the fact of the deteriorated character of the herbage, as shown by the results of the botanical examinations recorded in the last Number of the Journal, but also by the evidence relating to the chemical composition of the produce.

alone' have no effect; that, in order to be efficacious, they must be accompanied by the *mineral constituents*, and that the effect is then proportional to the supply—not of ammonia, but of the *mineral substances*."—*Principles*, p. 55 (1855).

"These two paragraphs are altogether irreconcilable; for if Mr. Lawes admit that the *mineral constituents* are indispensable to plants, how can he maintain that these very *mineral constituents* are replaceable by *ammonia*, that is to say, that by means of ammonia we can altogether dispense with them?"—*Principles*, p. 89 (1855).

"It has been mentioned in the preceding part of the chapter, that animal excrements may be replaced in agriculture, by other materials containing their constituents. Now, as the principal action of the former depends upon their amount of *mineral food* so necessary for the growth of cultivated plants, it follows, that we might manure with the *mineral food* of wild plants, or, in other words, WITH THEIR ASHES [the capitals are Baron Liebig's own]; for, these plants are governed by the same laws, in their nutrition and growth, as cultivated plants themselves."—3rd Edition, p. 183 (1843).

"But the weight or amount of the crops is in proportion to the quantity of food of both kinds, *atmospheric* and *mineral*, which is present in the soil, or conveyed to it in the same time. By manuring with *ammoniacal salts* a soil rich in available *mineral constituents*, the crops are augmented in the same way as they would have been if we had increased the proportion of *ammonia* in the air."—*Principles*, p. 77-8 (1855).

These sentences will be sufficient to show whether or not Liebig is justified in now attempting to fall back, in agricultural discussions, upon the more strictly scientific meaning of the terms "*mineral*" and "*inorganic*," so as to include within them "*ammonia*," "*ammoniacal salts*," "*atmospheric constituents*," &c., and thus to give a new definition to his mineral theory, or rather substitute at this date for his own theory, which has proved to be erroneous, another not his own.

The experiments with nitrate of soda (Plots 6 and 7) were commenced two years later than those with the other manures, so that we have the results of only five instead of seven years to record. Unlike those with ammonia-salts alone, however, we have, so far, indication rather of progressive increase than decrease of annual effect. There is also, as yet, rather more of produce and increase from a given amount of nitrogen applied in the form of nitrate of soda (Plot 7), than from an equal amount in the form of ammonia salts (Plot 4). The description of plants developed was, moreover, very different in the two cases. These results may be partly due to the fact that the soil having less power to absorb and retain the nitric acid of the nitrate than the ammonia of the ammonia-salts, the former would probably be more rapidly diffused in the soil, and hence minister to the wants of plants whose roots take a wider range than those of the plants most benefited by ammonia salts.

The experiments with superphosphate of lime alone (Plot 3a), and with superphosphate of lime and ammonia-salts (Plot 3b), were commenced three years later than most of the others, so that the results recorded refer to the produce of four years only.

The average annual increase with the superphosphate of lime alone was little more than 2 cwts. of hay per acre; and the produce has fluctuated, from year to year, much in the same degree as that without manure, excepting that in the fourth season (1862) the produce scarcely exceeded the average without manure.

The addition of ammonia-salts to superphosphate of lime, raised the average annual produce from $28\frac{1}{2}$ cwts. to $43\frac{1}{2}$ cwts., and the average annual increase beyond the produce without manure from a little more than 2 cwts. to nearly $17\frac{1}{2}$ cwts.

When to superphosphate of lime, salts of potass, soda, and magnesia were added (Plot 8), the average annual produce was raised from $28\frac{1}{2}$ cwts. to $36\frac{1}{2}$ cwts. of hay per acre; but the increase under these circumstances consisted almost wholly, if not exclusively, of Leguminous plants—clovers, meadow vetchling, and bird's-foot trefoil. Both the average produce and average increase were rather higher during the last four years than over the whole seven years of the experiments, and there is as yet no sign of diminution. In fact, this "mixed mineral manure" supplied annually more of all the mineral constituents otherwise most likely to be exhausted than would be taken off in the increased produce of Leguminous plants.

The addition of sawdust to the mixed mineral manure (Plot 9) scarcely added at all to the produce. It should be observed, in regard to the manuring of this plot, that in 1862 the potass-salt was omitted, and a larger quantity of soda-salt substituted, and the result was (as shown in the last Number of the R. A. Journal)

a notable diminution in the proportion of Leguminous herbage, though the total yield of hay per acre was not diminished.

The addition of 400 lbs. of ammonia-salts (equal parts sulphate and muriate) to the mixed mineral manure of Plot 8 (Plot 10) increased the average annual produce over the last four years from $36\frac{1}{2}$ cwts. to $53\frac{3}{4}$ cwts. of hay, that is, by about $18\frac{1}{2}$ cwts; and the average annual increase obtained by this mixture, above the produce without manure, was nearly $28\frac{1}{2}$ cwts. over the last four, and rather more than $31\frac{1}{2}$ cwts. over the whole seven years. There is, therefore, when this large amount of ammonia-salt is used in conjunction with the mixed mineral manure, an indication of a slight falling off in the annual yield. In reference to this point it should be particularly borne in mind, that whilst the produce by the mixed mineral manure alone contained Leguminous herbage in amount equal to nearly one-fourth of its total weight, that grown by the mixed mineral manure and ammonia-salts contained scarcely a trace of such herbage. The produce in the latter case consisted (with the exception of a few luxuriant weeds), almost entirely of Gramineous plants, or grasses, properly so called, which require a large amount of silica for their development; and as the manure employed contained none, the large amount of increase must have caused a considerable drain of the available silica of the soil, the limitation of the supply of which probably set a limit to the amount of increase obtained by this otherwise heavy manuring.

The addition of 2000 lbs. of sawdust per acre per annum to the mixed mineral manure and ammonia-salts (Plot 11) very little affected either the amount or the character of the produce, which was, however, rather less than without the sawdust. On this Plot 11, as on Plot 9, the potass-salt was omitted from the manure in 1862, but the amount of soda-salt increased, and about 2 cwts. less hay were obtained than on Plot 10 with the potass and without the sawdust. This difference is, however, but small; and although (not having at present at command either the analytical details relating to the first crop, or the results relating to the after-grass) we do not record the amounts of the first crop of the present season (1863), it may be mentioned in passing that Plot 11, without potass, has this year given a somewhat larger amount of Gramineous hay than Plot 10 with it.

The general result in regard to the effects of these mixtures of mineral constituents and ammonia-salts (Plots 10 and 11) is, that, by their means, we have obtained for seven or eight years consecutively, an average produce of about $2\frac{1}{2}$ tons of hay per acre, and an average increase of about $1\frac{1}{2}$ ton.

Adding to the same mixture of mineral constituents and ammonia-salts 2000 lbs. of cut wheat-straw annually, scarcely

increased the average produce of hay, notwithstanding that the straw was calculated to furnish, by gradual decomposition, besides other mineral constituents, the silicates in which the artificial mixture was deficient, and to contribute a supply of carbonic acid for the solution of the mineral constituents of the soil, and a small amount of available nitrogen also. The after-grass has, however, generally been slightly more luxuriant; and, as shown in the last number of the Journal, the description of herbage developed was somewhat different, and, perhaps, rather superior.

On Plot 13 (divided in 1862 into 13a and 13b), in addition to the mixed mineral manure, there was applied a double or very excessive amount of ammonia-salts (800 lbs.) in the first, second, third, and seventh years of the experiments, but only 400 lbs. in each of the three intermediate years, 1859, 1860, and 1861. The result of this very heavy dressing was an average over the seven years of above 3 tons of hay per acre per annum. It was somewhat less during the last four years, in three of which the single amount only of ammonia-salts was used; but in 1862 (and in the present year also) the produce was again increased with the increased supply of ammonia-salts, though by no means in proportion to that increased supply. As shown in the last number of the Journal, the heavy crops grown on this plot contained not a trace of Leguminous plants; but, with the exception of a few very luxuriant weeds, they consisted almost entirely of comparatively few species of very free-growing grasses, in an over-luxuriant and very stemmy condition.

As just alluded to, in 1862, that is, after the experiments had been continued for six seasons, this Plot 13 was divided into two equal portions; and to one of these (13b) 200 lbs. of a silicate of soda, and 200 lbs. of a silicate of lime, were applied per acre, in addition to the manures of Plot 13a. This led to scarcely any appreciable increase in the first year of the application, but the results of the present or second season show an increased produce of about 6 cwts. of hay per acre where the silicates were used; and it was obvious to the eye that some of the grasses were more luxuriant. It remains to be seen what will be the effects of this addition in future years. There is no doubt that the heavy dressing of 13a, without silicates, forcing, as it does to such a degree, the luxuriant growth of Gramineous plants, which require more silica than herbage of any other description, must tax very severely the store of available silicates within the soil. Additional evidence will be given on the point further on; but it may be here remarked in passing, that the forcing of very heavy crops of hay by the use of artificial manures alone is by no means recommended.

It would be far too expensive to supply in this way all the constituents that are requisite for the production of such crops without undue exhaustion of the soil, or deterioration in the character of the herbage. Artificial manures can, as a rule, only be used with advantage and economy for the hay crop, when the land receives periodically a dressing of stable or farmyard manure. Such manure restores the mineral constituents taken from the land in the crop more completely, and some of them more economically, than any other; it at the same time supplies a large amount of available nitrogen, and of organic matter yielding by its decomposition carbonic acid, and is calculated to favour a more complex and generally a superior description of herbage.

Plot 14 received the same description and amount of mineral manure as Plots 8, 10, 12, and 13a, and, in addition, nitrate of soda containing about half the amount of nitrogen supplied in the ammonia-salts of Plot 10; and Plot 15, with the same mineral manure, had, in addition, double the amount of nitrate—that is, about the same amount of nitrogen as that in the ammonia-salts of Plot 10. These experiments, like those with nitrate of soda alone, were commenced only in 1858, two years later than most of the series. The figures show an average over the five years of 44 cwts. of hay per acre per annum with the smaller amount of nitrate, and the mineral manure, and of 51½ cwts. with the larger amount, against 56½ cwts. with the same mineral manure, and ammonia-salts equal in nitrogen to this larger amount of nitrate.

Ammonia-salts, in conjunction with the mixed mineral manure, have, therefore, given a larger amount of produce than an equal amount of nitrogen in the form of nitrate of soda. The description of herbage developed was, however, strikingly different in the two cases, and very different also with the smaller and the larger amounts of nitrate, as will be found by reference to the last number of the Journal. It should be added, that there is as yet no evidence of diminution of produce from year to year where the nitrate (either in the larger or the smaller quantity) was used in conjunction with the mixed mineral manure.

The plots manured with farmyard manure remain to be considered. The amount annually supplied (14 tons) would contain more of every mineral constituent, and considerably more nitrogen, than the produce obtained by its use, besides a large quantity of organic matter yielding by its decomposition carbonic acid and other products. When the farmyard manure was used without the addition of ammonia-salts, the average annual produce amounted to only about 42½ cwts. of hay, or to less than 1 ton above that without manure, and to considerably less than was

obtained by the most active artificial manures. The description of herbage was, however, very different—that grown by the farmyard manure being very much more complex and, upon the whole, superior in quality to that grown by the very active artificial Manures.

The addition of 200 lbs. of ammonia-salts to the comprehensive, but not very rapidly active, farmyard manure increased the average annual produce by only about 6 cwts. of hay; still, therefore, giving a produce considerably less than that obtained by the most active artificial manures. Nor did the addition of ammonia-salts improve the character of the herbage, which was more Gramineous, consisted in larger proportion of comparatively few species, and was much more stemmy, than when the farmyard manure was used alone. The number, and proportion in the produce, of miscellaneous or weedy plants was, however, considerably reduced under the influence of the ammonia-salts.

Reviewing the results of the whole series, it is observed that the average produce without manure is slightly higher over the last four than over the whole seven years of the experiments; indicating, therefore, that the conjoint resources of soil and season were at least equal, if not more favourable, during the later years. A similar result is observed in the case of the farmyard manure plot, and of the plots where there was a liberal supply of mineral constituents without ammonia in the artificial manures; but where ammonia-salts were used in large quantity, either alone or in conjunction with the mineral manures, there was a tendency to a rather diminished rate of increase as the experiments proceed. The indication, so far as the gross amount of hay obtained is concerned, is, however, as yet but slight; and in the present season (1863) the produce on Plot 13a, where the very excessive amount of ammonia-salts was used, and where the mineral manure contained no silicates, is heavier than in any previous season. The chief indication of exhaustion of certain constituents, or of deterioration of the produce, is afforded by a consideration of the description and composition of the herbage developed. Where nitrate of soda is used, whether alone or in conjunction with the mixed mineral manure, there is as yet no evidence of progressive falling off in the annual yield.

Produce of After-Grass.

Table II. (p. 30) shows the amounts of hay per acre to which the after-grass of each of the last four seasons is estimated to be equivalent, and also the annual average over the four and over the seven years of the experiments. As already mentioned, the after-grass was always consumed by sheep (once or twice, as might be

required), so that the estimation of the quantity of hay to which it corresponded is necessarily a matter of calculation merely. The plan adopted was—to fold sheep on each plot, the number depending upon the amount of grass; to move the hurdles day by day as required; to note the time taken to consume the produce; and then to estimate, approximately, the amount of hay to which the consumed grass was equivalent, on the assumption that each sheep would, on the average, consume grass equal to 16 lbs. of hay per head per week. Such an estimate, though only approximate, still affords a very useful indication of the relative, if not the actual, amounts of after-grass of the respective plots. In 1860 and 1862 it was so eaten off twice, but in each of the other years only once.

It will be obvious that, as the animals would return to the land by far the larger proportion of both the mineral constituents and the nitrogen of the produce, to serve as manure for the first crop of the succeeding season, and so on each year, the amounts of hay estimated as above described cannot be added to the actual amounts of the first crop, and the sum reckoned as the annual yield on the respective plots. The latter would, however, it is true, be somewhat higher than the amount of first crop hay alone.

Judging from the relative amounts of first-crop hay where the mineral constituents would probably be in relatively large amount (without manure, with purely mineral manure, or with farmyard manure, for example), and where, therefore, the produce would be the more directly limited by the conditions of season, it would be concluded that these were the least favourable in 1859, more so in 1860, and still more favourable, and about equally so, in 1861 and 1862. Judging, in the same way, from the estimated amounts of hay corresponding to the after-grass, it would appear that the period of its growth was the most favourable in 1860, and nearly equally so in 1862 (these being the two years in which the produce was eaten off twice), that it was somewhat less favourable in 1861, and less so still in 1859. But it is obvious that the influence of accumulation, or of non-exhaustion of previous manuring, as well as that of season, has to be taken into account as affecting the produce in one year compared with another. The less the exhaustion of the more active manurial constituents by the growth of the first crop, the greater will be the accumulation for the after-growth, though their activity will greatly depend on the climatic conditions. And, again, variations in the amount of after-grass will affect the amount of manure left by the animals on the surface of the land, to be washed in and serve for the first crop of the succeeding year; though it will be obvious that any effects of such variation will

be due to the condition and distribution of the constituents rather than to any actual loss or gain of them.

The produce of after-grass was, upon the whole, the largest in 1860, when it was eaten off twice—the first time early in September. In accordance with this, the records show that in the months of July and August the maximum temperature was comparatively low, the minimum temperature moderate, the mean temperature and the range of temperature both low, and the fall of rain and the number of days on which it fell above the average. In 1862, also, the grass was fed off twice, commencing the first time soon after the middle of August; and the characters of the July and August of that season more nearly approached those of 1860, as above quoted, than did those of either of the other years. In 1859 the after-growth was both the smallest in amount and the latest, the sheep not being put upon the land at all until November 14; and coincidently with this there was comparatively high temperature, and somewhat below the average amount and distribution of rain—especially during the first few weeks after the removal of the hay-crop. In 1861 the amounts of after-grass were more than in 1859, but less than in either 1860 or 1862, and the produce was eaten off only once—namely, early in October. The characters of the season in regard both to temperature and amount of rain were less favourable for succulent growth than in either 1860 or 1862, and as to amount of rain less favourable than in 1859 also. In regard, however, to the distribution of rain, or the number of days on which it fell, the month of July (1861) was far above, and that of September about, the average.

From these few observations it will be obvious that the variations in the amounts of after-grass in one year compared with another were very directly dependent on the characters of the seasons; they were, in fact, much more so than on the greater or less amounts of hay removed in the first crop. It is, indeed, remarkable how little was the fluctuation in the produce of first-crop hay from season to season, with one and the same manure, compared with that of the after-grass. The character of the herbage of the first crop was, however, remarkably affected by the character of the season of its growth; one and the same amount of produce representing a very different description of hay in the different years. The variation manifested itself not only in a difference in the prevalence of particular plants, but more strikingly in the character of their development—the relative tendency to give a leafy or stemmy, base-leaved or stem-leaved, early or late, ripe or unripe produce. But the gross amounts of after-grass varied exceedingly from

year to year. In 1860 they amounted on the average to twice as much as in 1859; in 1861 to considerably less than in 1860, but generally to at least $1\frac{1}{2}$ time as much as in 1859; and in 1862 in most cases to nearly as much and in some to considerably more than 1860.

Without manure, the after-grass of 1859 was estimated as equal to something less than 8 cwts., that of 1860 about 19 cwts., that of 1861 nearly 14 cwts., and that of 1862 about $15\frac{1}{2}$ cwts. of hay. With farmyard manure the amounts were scarcely 10 cwts. in 1859, more than $21\frac{1}{2}$ cwts. in 1860, nearly 16 cwts. in 1861, and over 21 cwts. in 1862. With the heavy dressings of mixed mineral manure and ammonia-salts they ranged from about 11 to nearly 15 cwts. in 1859, from over 21 to over 22 cwts. in 1860, from about 16 to about 18 cwts. in 1861, and from about 17 to about 24 cwts. in 1862.

Comparing more directly the effects of the different manures on the amounts of after-grass, it is seen that the quantities varied, in 1859 from under 8 cwts. without manure to about $14\frac{1}{2}$ cwts. with the heaviest artificial manuring; in 1860 from about 19 cwts. to about 22 cwts.; in 1861 from about $13\frac{3}{4}$ cwts. to over 18 cwts.; and in 1862 from about $15\frac{1}{2}$ cwts. to about $24\frac{1}{2}$ cwts.

The facts relating to the after-grass show, then, that the amounts varied very much both according to season and manuring, and that, when both were favourable, they were frequently equivalent to more than one ton of hay. Taking the average of the seven years, the after-grass without manure was estimated as equivalent to about $12\frac{1}{2}$ cwts. of hay per acre per annum, and that with the heaviest artificial manuring at nearly $19\frac{1}{2}$ cwts.

Chemical Composition of the Hay.

In our former report on the composition of the hay grown by the different manures in the earlier years of the experiments (R. A. Journ. vol. xx., part 2), we treated of the proportions of—nitrogenous substance, fatty matter, woody fibre, other non-nitrogenous vegetable compounds, mineral matter (ash), total dry substance, and water; and to that more complete consideration of the subject we refer the reader. In treating, on the present occasion, of the composition of the hay grown in the fourth, fifth, sixth, and seventh seasons, attention will be confined to the proportions of dry matter, of mineral matter (ash), and of nitrogen; and a few general observations on the circumstances affecting the composition may here be made, thereby rendering the indications of the results themselves the more readily understood.

Comparing the hay of one season with that of another, a high

percentage of dry matter may simply indicate dry weather at the time of cutting and during the making ; or, it may also indicate a relatively high degree of maturity or ripeness. Comparing the produce of one plot with that of another differently manured, but grown in the same season, and cut and made under the same conditions of weather, a relatively high percentage of dry substance indicates a comparatively high degree of ripeness or maturity, and most probably a stemmy rather than a leafy condition of development.

As the percentage of mineral matter or incombustible constituents, even though the same in the fresh hay, may be very different in its dry substance, according to the proportion of the latter, and as the percentage in the dry substance indicates much more clearly the probable condition of the hay, it is important that it, as well as that in the fresh hay, should be considered. Other things being equal, a high percentage of mineral matter in the dry substance indicates a leafy rather than a stemmy development, and an immature rather than a ripe condition. The percentage of mineral matter in the produce is also more or less, though comparatively slightly, affected by the liberality or deficiency of available mineral constituents within the soil ; but as the tendency of the development is very much affected by these circumstances, the effects are, in part at least, indirect ; that is to say, the relative supply of mineral constituents, affecting as it does the relative development of leaf and stem, and the tendency to ripen, the percentage of mineral matter in the produce is in its turn affected accordingly, as above referred to.

The percentage of nitrogen in the dry substance of the hay may depend on several different conditions. The condition of manuring being the same, a high percentage in the produce of one year compared with that of another will most probably indicate a high proportion of leaf to stem, or a green and succulent rather than a ripened condition. Comparing the produce by one manure with that of another in one and the same season, the percentage may again depend on various circumstances. Leguminous plants, and some weeds, are much richer in nitrogen than Gramineous plants in an equal condition of ripeness ; leafy matter generally contains a higher percentage than stemmy ; succulent and unripe produce a higher one than that which is ripe (all of which conditions are much influenced by the character of the manure) ; and further, when in the succulent and unripe condition, as produce cut for hay to a certain extent is, the percentage of nitrogen is generally pretty directly affected by the relative available supply of it within the soil. That is to say, an excessively nitrogenous manure will—other things being equal—give a relatively high percentage of nitrogen at an

equal stage of growth or maturity ; but as, within limits, and under favourable conditions of soil and season, a moderate supply of nitrogen favours the ripening tendency, the crop more liberally dressed with nitrogenous manure may, at the same period of time, be at a more advanced stage of growth, and it might not then, as it otherwise would, show a higher percentage of nitrogen in its dry substance.

Percentage of Dry Matter in the Hay.

Table III. (p. 31) gives, for each plot, the per centage of dry matter in the hay as carted from the land, in each of the last four years, also the average percentages over the four, and the whole seven years of the experiments.

Comparing the produce of one year with that of another, the order of highest percentage of dry matter was—1859, 1861, 1860, and 1862 ; and it may be observed that this result is quite consistent with the characters of the respective seasons for some time before cutting, and during the making the hay. The percentages of mineral matter in the dry substance will, however, show, that there was a real difference in the ripeness of the produce, as well as in its mere condition of dryness or dampness according to the weather immediately before the cutting and during the making. Thus, the produce of 1859 and 1861, with higher percentages of dry matter than in that of 1860 or 1862, contained lower average proportions of mineral matter in the dry substance, indicating a greater degree of maturity.

The percentage of dry matter in the produce varied very much less comparing that grown by different manures in the same season, than comparing season with season. In fact, when it is borne in mind how many circumstances affect the condition of such complex and indefinitely ripened produce as hay according to the manure employed, it is only what we should expect, to find that the difference in the condition of the produce of two comparable plots may vary, or even be reversed, according to the characters of the season ; for, not only will the proportions of Leguminous, Gramineaceous, or other herbage (which are each somewhat differently affected in development according to season) be very different according to the manure employed, but the prevalence of one Gramineaceous plant over another, the tendency to leafy or stemmy growth, and the relative condition of ripeness, will also greatly vary. Thus, with a hot and ripening season, the addition of nitrogenous to mineral manure may so increase the fixation of carbonaceous substance as to give a produce containing a higher proportion of dry substance ; whilst in a wetter and colder season the effect would probably be to give a relatively leafy and succulent

growth, containing a lower percentage of dry matter. Accordingly, the relative proportions of dry matter in the produce of one plot compared with that of another are seen to vary more or less from season to season. Still the general, though not the invariable, result is found to be that, in comparable cases, the larger the relative supply of available mineral constituents, the higher will be the percentage of dry matter in the produce at the time of cutting, due mainly to the greater tendency to ripen under such conditions. The columns showing the average percentage of dry matter in the produce of each plot over the four and over the seven years afford sufficient illustration on this point.

The general result in regard to the proportion of dry matter in the hay is, that variation of season has very much more influence than variation in manure in one and the same season; that, so far as manures have an influence, those which tend most to stemmy produce, and to ripeness, generally give the highest proportion of dry substance; that a relatively liberal supply of mineral manure favours this tendency; and, that the greater the excess of nitrogenous manure (provided the supply of mineral constituents be not insufficient for luxuriant growth), the lower, other things being equal, will be the proportion of dry matter in the produce.

Percentage of Mineral Matter (Ash) in the Hay.

Table IV. (p. 32) shows the percentages of mineral residue obtained on burning the dry substance to ash, and the results approximately represent the relative proportions of mineral constituents. The left division gives the percentages in the hay as taken from the land, and the right those in the dry substance of the hay. The latter of course give the best view of the relations of the mineral to the other solid constituents of the produce.

Comparing season with season, there were much lower proportions of mineral matter in the dry substance of the ripper and drier produce of 1859 and 1861, than in that of the more backward and moister produce of 1860 and 1862; and, of the four seasons, the produce of 1862, which yielded the lowest proportion of dry substance, shows generally, but not invariably, the highest proportion of mineral matter in that dry substance.

Comparing plot with plot, the percentage of mineral matter in the dry substance of the hay has a very obvious connexion with the conditions and characters of growth.

The general result in regard to the proportion of mineral matter in the dry substance of the hay may be stated to be, that it was the higher the more liberal the relative supply of mineral constituents in the manure, the less Graminaceous, or the less

ripe the produce, and that it was lower in the opposite conditions. Combinations of these several conditions (the two latter of which are each much influenced both by season and manure) determine the actual character of the produce in regard to the point in question.

Percentages of Nitrogen in the Hay.

Table V. (p. 33) shows the percentages of nitrogen in the produce of each plot in each of the four years under consideration, also the average over the four years, and the average over the seven years; the left hand columns give the proportions in the hay as taken from the land, and the right hand ones those in the dry substance of the hay.

It has been already stated—that Leguminous produce, in an equal condition of ripeness, gives a higher percentage of nitrogen than Gramineous produce; that, other things being equal, the more leafy or more unripe the crop, the higher will be the percentage of nitrogen in the dry substance; and that, in succulent and unripe produce more especially, the proportion may be much increased by a liberal or an excessive supply of nitrogen in manure. Keeping in view these few facts, the variations exhibited in the Table become intelligible; and it will be observed that they are less directly traceable to the characters of the seasons, and much more dependent on variation in manuring, than are those of either the dry substance or the mineral matter.

In fact, the general result may be stated to be, that there was much less difference from year to year depending upon season, than between the produce of different plots in one and the same season depending on difference in manuring; that, other things being equal, the more complex and the less Gramineous the herbage (conditions favoured by mineral manures), the more leafy, the less ripe, and the more excessive the nitrogenous manuring, the higher was the percentage of nitrogen; that the more Gramineous, the more stemmy, and the more ripe (conditions favoured by farmyard-manure, and by artificial combinations of both mineral and nitrogenous manure), the lower was the percentage of nitrogen.

It was fully explained in our former paper on this subject, that a percentage of nitrogen in meadow-hay much beyond that found in the produce grown without manure, or by farmyard-manure, is by no means a sure indication of a proportionally increased amount of matured and digestible or assimilable nitrogenous substance. When the increased percentage of nitrogen is due to a large proportion of Leguminous herbage, it will probably indicate a large proportion of nutritive nitrogenous

compounds; but when it is the result of excessive nitrogenous manuring, the produce is then almost exclusively Gramineous and comparatively immatured; and, under such circumstances, a certain portion of the nitrogen may exist in a low condition of elaboration, and a high proportion may, in fact, represent a deficient accumulation of other matters rather than a favourable development of nutritive nitrogenous substance. A percentage of nitrogen in meadow-hay beyond that obtained without manure or by means of farmyard-manure is, therefore, under such conditions, not to be taken as evidence of higher feeding value. The value of the manure voided by the animals feeding on the hay, will, however, be the higher the higher the proportion of nitrogen it contains—especially as it so happens that there is generally with a high percentage of nitrogen a high percentage of mineral matter also.

Produce of Constituents per Acre.

As pointed out in our former report, particular interest attaches to the question of the amount of constituents taken from an acre of land in the hay-crop, because very frequently the system of restoration adopted in the case of the meadow-land of a farm is even less satisfactory than in that of the land under rotation; hence it becomes necessary to impress upon the farmer how great is the exhaustion to which his meadow-land may be subject.

Tables VI., VII., and VIII. (pp. 34, 35, 36) show, respectively, the amounts of dry substance, of mineral matter, and of nitrogen, removed per acre from each of the experimental plots, in each of the last four years; also the average amounts per annum, both in the produce and in the increase by manure, over the four years, and over the whole seven years of the experiments.

Over the seven years, there has been removed per acre annually from the unmanured land an average of 2358 lbs. (about 21 cwt.) of dry substance, containing $167\frac{1}{2}$ lbs. ($1\frac{1}{2}$ cwt.) of mineral matter, and nearly 40 lbs. of nitrogen. This amount of dry substance is somewhat higher than the average of the first three years of the experiments; but it agrees very closely with, though it somewhat exceeds, the amounts annually taken from the land in wheat or barley grown year after year without manure. The above amounts of mineral matter and nitrogen are, however, each fully one-half more than are removed in wheat or barley grown under such circumstances.

The unmanured produce of hay would contain between 900 and 1000 lbs. of carbon. By the use of ammonia-salts alone, or

nitrate of soda alone, the amount of carbon annually removed in the crop was increased to something under or over 1300 lbs., and by means of the mixed mineral manure alone to about the same amount; but by the mixtures of both ammonia-salts and mineral manure it was increased to over 2000 lbs. per acre—that is, without any supply of carbon in the manure. The addition to the latter manures of 2000 lbs. of sawdust, or 2000 lbs. of cut wheat-straw, each containing in round numbers about 700 lbs. of carbon, gave no increased yield of it in the produce. Nor did farmyard-manure, in amount containing at least twice as much carbon as the crop yielded by its use, give a produce containing more than about three-fourths as much as the mixtures of mineral manure and ammonia-salts which supplied none. It may be concluded, therefore, that, even admitting that the carbonaceous manures did supply carbon to the growing plants, the supply from that source was at any rate unnecessary, provided only that mineral or incombustible constituents, and nitrogenous manures were liberally supplied.

As mentioned above, the average amount of mineral or incombustible constituents taken from the land without manure was, over the seven years, $167\frac{1}{2}$ lbs., or about $1\frac{1}{2}$ cwts. per acre per annum. The amount removed in the crop grown by means of ammonia-salts alone was increased to something under, and that by nitrate of soda alone to something over, 2 cwts.; there being, therefore, by such manuring, a further drain upon the resources of the soil.

By means of the mixed mineral manure alone, the amount of incombustible constituents taken away in the crop was raised to about $2\frac{1}{2}$ cwts.; but the manure itself supplied more of almost every such constituent, except silica, than the entire produce would contain; so that, excepting in the item of available silica, the soil was, compared with the unmanured land, annually accumulating most of the important mineral constituents. By the addition of ammonia-salts to the mixed mineral manure, the amount of mineral constituents taken from the land was raised from about $2\frac{1}{2}$ to nearly $3\frac{1}{2}$ cwts. when the smaller amount (Plot 9), and to nearly 4 cwts. when the larger amount of ammonia-salts (Plot 13a) was employed; and, as the produce was in these cases almost entirely Gramineous, the drain upon the available silica of the soil would be very considerable; though, here again, all the other incombustible constituents were supplied in far larger quantity than they were taken off in the crops. By the addition of nitrate of soda to the mixed mineral manure, whether in the smaller amount (Plot 14), or in the larger amount

equal in nitrogen to the ammonia-salts of Plot 9 (Plot 15), the quantity of mineral constituents taken from the land was somewhat less.

Lastly on this point: by means of an annual dressing of farmyard-manure, doubtless supplying much more of every mineral constituent than was contained in the crop yielded, rather under 3 cwts. of incombustible constituents were annually taken from the land; and, when to the farmyard-manure ammonia-salts were added, the amount was raised by only $43\frac{1}{2}$ lbs.—that is, from $328\frac{1}{2}$ to $372\frac{1}{2}$ lbs., or to less than when the artificial mixtures of mineral manure and ammonia-salts were employed.

The result is, then, that without manure the land yielded, over seven years, about $1\frac{1}{2}$ cwt. of mineral constituents per acre per annum, the amount increasing rather than diminishing in the later years; that farmyard-manure supplying, besides other matters, more of every mineral constituent than the produce obtained by its use, gave a crop containing about twice as much; and that artificial mixtures containing both mineral constituents and ammonia-salts gave a still larger yield, even when no silicates were supplied in the manure.

It is obvious, that when purchased nitrogenous and phosphatic manures, such as Peruvian guano, or mixtures of ammonia-salts or nitrate of soda and superphosphate of lime, are alone relied upon for the increased crop of hay, the drain of potass and available silica from the soil must be very great. This was illustrated in some detail in our former report, by reference to the analyses of the ashes of the hay grown by the different manures; and confirmatory evidence of the injurious effects of such exhaustion will be found on comparing the average annual amounts of mineral matter taken from each plot over the seven with that over the last four years. Thus, whilst without manure, with mixed mineral manure, and with farmyard-manure, the average amount of mineral constituents annually taken from the land was greater during the later years than during the whole period of the experiments, it was (with one exception) less in the later years wherever large quantities of ammonia-salts were employed. A similar result is not as yet observable when nitrate of soda has been used; but, as already explained, it is probable that some of the plants then developed would draw their nutriment from a more extended range within the soil; and, if so, a diminution in the annual yield may be only a little postponed.

These results in regard to the mineral constituents taken from the land in the hay crop, clearly show how important it is that due restoration should be made, if the character of the herbage and the amount of crop are to be maintained. This is best accomplished in practice by an occasional dressing of well rotted

stable or farmyard-manure. Taking into account the other constituents at the same time thus supplied, silica and potass are more advantageously and economically provided in this form than in any other; and, as the results with the farmyard-manure show, the increase which a given quantity annually yields, removes but a small amount of mineral constituents compared with that which it supplies, so that the effects extend over several years, causing, unless specially nitrogenous manures be also applied, an accumulation within, rather than an exhaustion of the soil. When farmyard-manure is so employed, a further increase of crop may, without detriment to the land, be annually obtained by the moderate application of the current artificial manures containing nitrogen and phosphoric acid; but to this point we shall recur presently.

Produce of Nitrogen per Acre.

Table VIII. (p. 36) shows the acreage amounts of nitrogen taken off in the crop of each plot, in each of the last four years, also the average annual yield, and the average annual increase of it, over the last four, and over the whole seven years. A comparison of the two columns, giving the annual average yield, shows that, in the majority of cases, it was almost identical over the last four, and the whole seven years. The agreement was the less close where the large amounts of ammonia were used in conjunction with mineral manure, by which very large crops were obtained. It is, however, only in the case of Plot 13a, where the very excessive amount of ammonia-salts was applied in the first, second, third, and seventh years, that the average yield of nitrogen is at all materially reduced during the last four, as compared with the seven years (98·3 lbs. to 85·8 lbs.). But, as the supply of nitrogen in the manure was reduced by one-half in three years out of the four, this is only what might be expected; and it is seen that, in the seventh year, when the larger amount of ammonia-salt was again employed, the yield of nitrogen per acre in the crop was considerably increased.

Taking the average over the seven years, the result is—that the yield of nitrogen per acre without manure was within a fraction of 40 lbs., or about $1\frac{1}{2}$ time as much as has been annually taken from an acre of unmanured land in either wheat or barley; that mineral manures alone increased the yield by nearly one-half, the increase being then due to the large amount per acre, and proportion in the produce, of the highly nitrogenized Leguminous herbage; that ammonia-salts alone (or nitrate of soda containing about an equal amount of nitrogen) increased it more than mineral manures alone, though Leguminous plants were then almost excluded, and the produce was almost wholly Grami-

naceous ; and that the mixtures of mineral manure and ammonia-salts (or nitrate supplying an equal amount of nitrogen), which gave a very much increased, and also an almost exclusively Gramineaceous produce, gave also the highest yield of nitrogen in the series—even more than a mixture of farmyard-manure and ammonia-salts, together supplying much more nitrogen.

The important question arises—What proportion of the nitrogen supplied in the manure is recovered as increased yield of it in the crop?

Proportion of the Nitrogen supplied in the Manure which is recovered as increased yield of it in the Crop.

In our former Report, with the average results over only three years before us, we showed that, under the most favourable conditions, the increased yield of nitrogen in the hay-crop scarcely reached, and in the average of cases fell short of, 50 per cent. of that supplied in the manure. But it was admitted that three years was too short an experience upon which to form a satisfactory estimate on the point. The calculations have now been made for the whole seven years of the experiments.

In Table IX. (p. 37) are recorded the actual amounts of nitrogen per acre (lbs.), and in Table X. (p. 38) the amounts for 100 in manure, which were recovered as increased yield of it, when known quantities were supplied, each being reckoned both over the yield without manure, and over that by mixed mineral manure alone ; and, for comparison, the average results over both the last four and the whole seven years are given.

It is obvious that, in a practical or economical sense, the only direct gain to the farmer of nitrogen in the produce by the use of mineral and nitrogenous manures together, is so much as is over and above the amount yielded by the same mineral manures when used alone. But, for reasons explained in our former Report, we deem it, upon the whole, the most consistent with what we know of the facts, to reckon at least so much of the nitrogen of the produce grown by nitrogenous manure as is over and above that yielded without manure, to have its source in the nitrogen supplied, whether the nitrogenous manure be employed alone, or in conjunction with mineral manure.

Reckoned in this way, Table X. shows that, when ammonia-salts were used alone (Plot 4), 27·4 per cent. only of the nitrogen so supplied was recovered as increased yield over the seven years, and very nearly the same proportion, 27·1 per cent., over the last four years. With salts of ammonia and sawdust (Plot 5), reckoning of course the nitrogen in the sawdust, the proportion recovered was rather less, but again about equal over

the seven and the last four years. With the smaller amount of nitrate of soda (Plot 6), the estimated return of nitrogen was 37.7 per cent., and with the larger amount (Plot 7) only 29.9 per cent, taking the average of the five years of its use; but over the last four years the figures show rather more recovered than when the first year is included. It is worthy of remark, that the proportion recovered with the larger amount of nitrate (Plot 7), is higher than with the corresponding amount of nitrogen in the form of ammonia-salts (Plot 4).

With the same amount of ammonia-salts as was applied to Plot 4 (400 lbs.), and the mixed mineral manure in addition (Plot 10), the increased yield of nitrogen estimated as attributable to that supplied was 46.5 per cent. reckoning over the seven, but only 43.4 per cent. over the last four years; indicating, therefore, that, even under these comparatively favourable conditions, the proportion recovered is diminishing rather than increasing from year to year. It is to be borne in mind, however, not only that the silica so specially required by Gramineous crops was not supplied in the mineral manure in question, but also that the amount of ammonia-salts annually used (400 lbs., containing about 82 lbs. nitrogen) was very large. It is remarkable, too, that although when used alone (Plot 4), the ammonia-salts gave a less return of nitrogen than nitrate of soda containing an equal amount of it (Plot 7), yet, when used in conjunction with the mixed mineral manure, the proportion estimated as recovered was less with the nitrate (Plot 15) than with the ammonia-salts (Plot 10). However, when the smaller amount of nitrate of soda was used with the mineral manure (Plot 14), the nitrogen estimated as recovered amounted to about 62 per cent. of that supplied; that is, to more than in any of the experiments where the larger amounts of nitrogen were supplied, which gave larger, though not proportionally larger, amounts of produce.

When to the mixed mineral manure and ammonia-salts, sawdust or cut wheat-straw (Plots 11 or 12) was added, and their nitrogen reckoned in the supply, the proportions estimated as recovered are less than when they are not employed.

Where the double or very excessive amount of ammonia-salts was applied in the first, second, third, and seventh years (Plot 13a), the proportion of nitrogen recovered was exactly the same over the seven years (and even more over the last four) as where the less amount of ammonia-salts with the same mineral manures was used (Plot 10). The increase of gross produce or hay was, however, not in proportion either to the increased supply or increased yield of nitrogen; the large yield of it being due to a very high—perhaps an objectionably high—

percentage in the produce in the years in which the large amount of ammonia-salts was used; in fact, it was then higher than in any other case where mineral manures were used in conjunction with ammonia-salts. The Table records the results of only one year (1862) in which, to this mixture of 800 lbs. of ammonia-salts and the "mixed mineral manure," silicates (so much exhausted by the hay crop) were added (13*b*), and the figures show almost exactly the same proportion of nitrogen recovered as in the same year without the silicates (13*a*).

Lastly, when ammonia-salts were added, in comparatively small or moderate amount, to a quantity of farmyard-manure itself containing a very large amount of nitrogen, the increased yield of nitrogen beyond that in the produce by farmyard-manure alone amounted, over the seven years, to only 21·9 per cent., and over the last four years to only 13·8 per cent. of that supplied in the ammonia-salts. It may be further remarked that, if the farmyard-manure employed be assumed to have been of fair average composition, the proportion of its nitrogen reckoned as recovered in the increased yield (beyond that without manure), reaches to even a still lower amount.

To sum up on this point, the average results taken over the seven years are, that, when the nitrogenous manures (ammonia-salts or nitrate) were used alone 29·9, and when in conjunction with the mixed mineral manure 45·1 per cent. of the supplied nitrogen were reckoned as recovered as increased yield of it in the crop. In our former Report, then taking the results of three years only, the amounts were 26·1 per cent. without, and 46·6 per cent. with the mineral manure. The result over the more extended period is, therefore, somewhat higher without, and somewhat lower with, the mineral manure. When ammonia-salts were superadded to an amount of farmyard-manure doubtless containing nitrogen, carbon, and every mineral constituent, in larger quantity than the crop it yielded (though in comparatively slowly available condition), the increased yield of nitrogen due to the ammonia-salts was then less than in any of the other conditions of their use; and it was considerably less over the later than over the earlier years. It may be remarked that nitrate of soda containing the same amount of nitrogen as that in the ammonia-salts added to the farmyard-manure, but used in conjunction with the mixed mineral manure, was reckoned to return nearly three times as much of the supplied nitrogen.

Before leaving the question of the amount of nitrogen estimated as recovered in the increase for a given amount supplied in manure, it should be observed that, inasmuch as the whole of the nitrogen of the after-grass is not returned to the land by the animals fed upon it, the amount will be

somewhat higher than that represented by the increase in the hay crop merely. But were it attempted to make allowance for this, the results would not differ very widely from those recorded in the Tables. For, not only would by far the larger proportion of the nitrogen of the after-grass be returned to the land, but it would be only so much of the remainder as was due to increase by manure, that would have to be taken into the calculation. Nor are the data requisite for such a mode of estimation sufficiently established to render any such supposed correction at all desirable. It is, however, well to make this reservation in regard to the figures recorded in the Tables.

It may be interesting here to observe that, in experiments with wheat conducted over six years, 43 per cent., and in others with barley, also over six years, 42·5 per cent. of the nitrogen supplied in the manure was estimated to be recovered as increased yield. Against these amounts the average result obtained with the meadow-hay over seven years was, in parallel cases, 45·1, which, raised by the small amount due to the after-grass, as above explained, would show that the mixed herbage of meadow-land probably gathers up within the season of application a somewhat larger proportion of the nitrogen supplied as manure than either wheat or barley.

In our former report we directed attention to the probable explanations of the real or apparent loss of nitrogen here indicated; and we would refer the reader to a discussion of the subject in a paper "On the Sources of the Nitrogen of Vegetation; with special reference to the question whether plants assimilate free or uncombined nitrogen," in the 'Journal of the Chemical Society of London,' Ser. 2, Vol. 1, 1863.

Upon the whole, the evidence goes to show, that stable or farmyard-manure is a much more perfect restorer of the constituents removed in the hay-crop than those purchased or so-called artificial manures which, in a practical or economical point of view, can be advantageously employed. Farmyard-dung is, however, comparatively slow in its action. These characters point to the peculiar fitness of such manure for meadow-land mown for hay; and it was shown in our Report in the last number of the Journal, that the description of herbage developed by it was much more complex, and upon the whole superior in quality, to that developed by the more active artificial manures. On the other hand, provided the restoration of the potass and silica of the hay-crop be duly accomplished by means of farmyard-manure occasionally applied, its slowness of action may

be advantageously compensated by a judicious use of some of the more active artificial or purchased manures.

In the experiments which form the subject of this paper, the amount of farmyard-manure annually employed was 14 tons per acre, which would doubtless contain very much more of every constituent of the hay-crop than the produce yielded. Under these circumstances, although the superaddition of ammonia-salts considerably increased the crop, they gave a less result than under any of the other conditions of experiment. If the same amount of farmyard-manure, or even less of well-rotted dung, were employed once in four or five years, this would supply sufficient of most of the mineral constituents for a larger amount of increase than would be obtained in several years by its use alone; and, under such circumstances, the additional application of moderate quantities of the more rapidly active manures, such as Peruvian-guano, or ammonia-salts or nitrate of soda and superphosphate of lime, would not only serve to bring into more rapid use the constituents of the dung, but the increase of crop would be obtained without injury to the permanent condition of the land, and with little detriment to the character of the herbage developed.

Under some circumstances ammonia-salts, and under others nitrates, seem to be the more active in proportion to the nitrogen they contain. But, as the mixed herbage of grass-land includes plants of very different habits of growth, seeking their nutriment at very different ranges within the soil, and as the nitrogen of nitrate of soda becomes distributed much more rapidly than that of ammonia-salts, it is desirable to employ a mixture of these two manures. By this means the growth of a greater variety of plants is favoured, and very probably a greater amount of increase will be obtained within a given time for a given amount of nitrogen applied.

Assuming the dung to be employed in quantity sufficient for the due restoration of the alkalies, alkaline earths, and silica, it would, of course, at the same time supply a considerable amount of phosphoric acid also. But experience shows that, even when this is done, activity of growth is frequently considerably increased if direct phosphatic manures be also employed. The phosphoric acid may be advantageously and economically applied either in the form of Peruvian guano, which at the same time supplies a large quantity of ammonia or ammonia-yielding matter and a little potass also, or as superphosphate of lime.

EXPERIMENTS at ROUGHAMSTED with DIFFERENT MANURES ON PERMANENT MEADOW LAND.
TABLE I.—PRODUCE of HAY per Acre; Tons, cwt., qrs., and lbs.

Plot Nos.	MANURES PER ACRE, PER ANNUM. (For detailed description, see pp 3, 4.)	Annual Produce.					Average Annual Increase by Manure.	
		1859.	1860.	1861.	1862.	Average.		
		Cut June 27; Carted July 6.	Cut July 7; Carted July 13.	Cut June 29; Carted July 3.	Cut June 25; Carted July 4-8.	Of 7 Years (1859-65).	Of 4 Years (1859-62).	Of 7 Years (1860-66).

SERIES 1.—Without Direct Mineral Manure.

		T. cwt. qrs. lbs.	T. cwt. qrs. lbs.	T. cwt. qrs. lbs.	T. cwt. qrs. lbs.	T. cwt. qrs. lbs.	T. cwt. qrs. lbs.	T. cwt. qrs. lbs.
1	Unmanured (duplicate plot)	1 3 30	1 4 3 16	1 5 1 16	1 7 2 8	1 4 3 27	1 4 4	1 4 3 27
2	Unmanured	1 3 30	1 5 3 0	1 9 3 0	1 10 2 8	1 7 0 23	1 6 0 15	1 7 0 23
3	Mean, or Standard Unmanured	1 3 30	1 6 0 22	1 7 1 29	1 8 3 18	1 6 0 11	1 5 0 24	1 6 0 11
4	500 lbs. each Sulphate and Murate Ammonia	1 13 2 4	1 6 1 0	1 14 0 0	1 14 1 18	1 13 0 23	1 13 0 23	0 5 2 23
5	500 lbs. each Sulphate and Murate Ammonia, and 2000 lbs. Sawdust	1 12 2 4	1 6 2 14	1 15 1 0	1 19 3 0	1 13 2 10	1 14 1 3	0 7 1 27
6	275 lbs. Nitrate of Soda	1 12 0 4	1 15 1 0	1 16 2 4	1 19 3 0	1 15 3 15	1 13 3 23	0 9 3 4
7	500 lbs. Nitrate of Soda	1 16 3 0	1 19 1 14	1 19 3 0	1 16 1 32	1 18 0 10	1 16 3 10	0 11 3 27

SERIES 2.—With Direct Mineral Manure.

		T. cwt. qrs. lbs.	T. cwt. qrs. lbs.	T. cwt. qrs. lbs.	T. cwt. qrs. lbs.	T. cwt. qrs. lbs.	T. cwt. qrs. lbs.	T. cwt. qrs. lbs.
8	Superphosphate of Lime	1 5 1 0	1 8 1 12	1 10 1 12	1 9 0 4	1 8 1 0	1 8 1 0	0 2 0 17
9	Sulphate of Lime, and 200 lbs. each Sulphate and Murate Ammonia	2 4 2 12	2 2 3 0	2 4 1 12	2 2 1 24	2 3 2 5	2 3 2 5	0 17 1 22
10	Mixed Mineral Manure, and 2000 lbs. Sawdust	1 10 2 0	1 12 0 8	2 0 0 8	1 19 2 0	1 16 1 4	1 14 3 27	0 10 0 21
11	Mixed Mineral Manure, and 200 lbs. each Sulphate and Murate Ammonia	1 10 1 8	1 16 1 14	2 1 0 14	2 0 1 16	1 16 2 9	1 16 2 9	0 10 3 23
12	Mixed Mineral Manure, and 200 lbs. each Sulphate and Murate Ammonia	2 15 1 10	2 10 0 24	2 16 1 16	2 17 0 18	2 14 3 3	2 16 3 1	1 8 2 20
13	Mixed Mineral Manure, and 2000 lbs. Sawdust	2 12 1 0	2 7 3 14	2 17 1 20	2 15 0 20	2 13 0 21	2 15 2 0	1 7 0 10
14	Mixed Mineral Manure, and 200 lbs. each Sulphate and Murate Ammonia	3 2 1 0	2 11 1 16	2 18 0 0	2 14 3 24	2 16 2 17	2 14 3 27	1 10 2 6
15	Mixed Mineral Manure, and 200 lbs. each Sulphate and Murate Ammonia	3 3 3 10	3 11 1 4	2 19 3 18	3 3 1 24	2 19 2 14	3 1 1 16	1 13 2 3
16	Mixed Mineral Manure, and 200 lbs. each Sulphate and Murate Ammonia	2 4 1 0	2 2 3 24	2 9 0 26	2 6 0 26	2 5 2 19	2 4 0 11	0 19 2 6
17	Mixed Mineral Manure, and 275 lbs. Nitrate of Soda	2 14 0 24	2 9 3 14	2 12 2 12	2 11 0 6	2 11 3 21	2 11 3 21	1 5 3 10
18	Mixed Mineral Manure, and 500 lbs. Nitrate of Soda	2 0 3 20	2 6 2 0	2 5 0 12	2 5 0 20	2 4 1 20	2 2 2 15	0 18 1 9
19	14 tons Farmyard Manure, and 100 lbs. each Sulphate and Murate Ammonia	2 7 3 8	2 10 3 20	2 7 2 0	2 9 2 12	2 6 3 24	2 6 3 8	1 2 3 13

SERIES 3.—With Farmyard Manure.

		T. cwt. qrs. lbs.	T. cwt. qrs. lbs.	T. cwt. qrs. lbs.	T. cwt. qrs. lbs.	T. cwt. qrs. lbs.	T. cwt. qrs. lbs.	T. cwt. qrs. lbs.
16	14 tons Farmyard Manure	2 0 3 20	2 6 2 0	2 5 0 12	2 5 0 20	2 4 1 20	2 2 2 15	0 18 1 9
17	14 tons Farmyard Manure, and 100 lbs. each Sulphate and Murate Ammonia	2 7 3 8	2 10 3 20	2 7 2 0	2 9 2 12	2 6 3 24	2 6 3 8	1 2 3 13

* With Sulphate of Potash excluded, and the amount of Sulphate of Soda increased, in 1862. † Only 200 lbs. each in 1859, 1860, and 1861. ‡ Average of 5 years only.

EXPERIMENTS at ROTHAMSTED with DIFFERENT MANURES on PERMANENT MEADOW LAND.

TABLE II.—SHOWING the QUANTITY of HAY to which the AFTER-GRASS (consumed by Sheep on the Land) is estimated to be equivalent; calculated on the assumption that each Sheep would eat Grass = 16 lbs. of Hay per Week.

Plot, No.	MANURES PER ACRE, PER ANNUM. (For detailed description, see pp. 3, 4.)	After-grass estimated as Hay (per Acre, per Annum).				
		1859, Second Crop.	1860, Second and Third Crop.	1861, Second Crop.	1862, Second and Third Crop.	Average, Of 4 Years (1859-62).
		lbs.	lbs.	lbs.	lbs.	lbs.
SERIES 1.—Without Direct Mineral Manure.						
1	Unmanured (duplicate plot)	914	2112	1835	1718	1844
2	Unmanured	823	2146	1864	1735	1857
4	200 lbs. each, Sulphate and Muriate Ammonia	868	2139	1845	1737	1840
5	200 lbs. each, Sulphate and Muriate Ammonia, and 2000 lbs. Sawdust	906	2222	1864	1846	1859
6	275 lbs. Nitrate of Soda	822	2228	1864	1846	1859
7	350 lbs. Nitrate of Soda	960	1507	1436	2304	1515
SERIES 2.—With Direct Mineral Manure.						
3a	Superphosphate of Lime	822	2112	1835	1893	1868
3b	Superphosphate of Lime, and 200 lbs. each, Sulphate and Muriate Ammonia	967	2223	1846	2157	1778
8	"Mixed Mineral Manure," and 2000 lbs. Sawdust	1254	2278	1792	1801	1834
9	"Mixed Mineral Manure," and 200 lbs. each, Sulphate and Muriate Ammonia	1254	2378	1792	1901	1834
10	"Mixed Mineral Manure," and 200 lbs. each, Sulphate and Muriate Ammonia, and 2000 lbs. Sawdust	1254	2434	1902	1863	1863
11	"Mixed Mineral Manure," 200 lbs. each, Sulphate and Muriate Ammonia, and 2000 lbs. Straw	1254	2434	1902	2003	1914
12	"Mixed Mineral Manure," 200 lbs. each, Sulphate and Muriate Ammonia, and 200 lbs. Cut	1254	2496	2021	2725	2084
13a	"Mixed Mineral Manure," and 400 lbs. each, Sulphate and Muriate Ammonia	1446	2434	2021	2725	2119
13b	"Mixed Mineral Manure," and 400 lbs. each, Sulphate and Muriate Ammonia, and 400 lbs. each	1446	2434	2021	2725	2119
14	"Mixed Mineral Manure," and 275 lbs. Nitrate of Soda	822	1576	1701	2304	1601
15	"Mixed Mineral Manure," and 350 lbs. Nitrate of Soda	960	2010	1728	2304	1750
SERIES 3.—With Farmyard Manure.						
16	14 tons Farmyard Manure	1098	2432	1755	2295	1920
17	14 tons Farmyard Manure, and 100 lbs. each, Sulphate and Muriate Ammonia	1098	2432	1755	2295	1920

* With Sulphate of Potash excluded, and the amount of Sulphate of Soda increased, in 1860.
† Only 200 lbs. each in 1859, 1860, and 1861.
‡ Average of 5 years only.

* With Sulphate of Potash excluded, and the amount of Sulphate of Soda increased, in 1862.

† Only 200 lbs. each in 1859, 1860, and 1861.

‡ Average of 5 years only.

EXPERIMENTS at ROTHAMSTED with DIFFERENT MANURES ON PERMANENT MEADOW LAND.
TABLE III.—PERCENTAGES OF DRY SUBSTANCE in the HAY (Means of Duplicate Determinations).

Plot No.	MANURES PER ACRE, PER ANNUM. (For detailed description, see pp. 3, 4.)	1859.	1860.	1861.	1862.	Average.	
		Cut June 27; Carried July 2.	Cut July 7; Carried July 12.	Cut June 26; Carried July 3.	Cut June 25; Carried July 4-6.	Of 4 Years (1859-62).	Of 7 Years (1856-62).
SERIES 1.—Without Direct Mineral Manure.							
1	Unmanured (duplicate plot)	88.7	82.9	83.3	78.5	83.9	84.0
2	Unmanured	86.5	79.7	84.1	79.5	82.4	83.5
4	200 lbs. each, Sulphate and Muriate Ammonia	87.5	81.3	84.7	79.0	83.1	83.8
5	200 lbs. each, Sulphate and Muriate Ammonia, and 2000 lbs. Sawdust	87.6	81.6	83.9	79.0	82.9	83.0
6	275 lbs. Nitrate of Soda	86.0	81.0	83.1	78.5	82.6	83.0
7	500 lbs. Nitrate of Soda	83.7	79.3	84.7	78.8	82.52	82.32
	Mean	85.0	80.5	85.0	77.5	81.4	82.32
	Mean	85.0	80.5	84.1	78.6	82.3	82.9
SERIES 2.—With Direct Mineral Manure.							
2a	Superphosphate of Lime	87.4	81.3	83.6	78.8	82.8	83.0
2b	Superphosphate of Lime, and 200 lbs. each, Sulphate and Muriate Ammonia	86.4	80.3	83.9	77.4	82.0	82.5
3	Mixed Mineral Manure	87.7	79.9	84.7	78.5	83.7	83.3
4	Mixed Mineral Manure, and 2000 lbs. Sawdust	87.6	81.2	84.0	79.3	83.0	83.4
5	Mixed Mineral Manure, and 200 lbs. each, Sulphate and Muriate Ammonia	83.9	83.9	83.7	79.0	81.7	82.1
6	Mixed Mineral Manure, and 200 lbs. each, Sulphate and Muriate Ammonia, and 2000 lbs. Sawdust	85.2	78.9	83.7	78.2	81.5	82.1
7	Mixed Mineral Manure, and 200 lbs. each, Sulphate and Muriate Ammonia, and 2000 lbs. Cut	87.0	78.4	83.7	79.7	82.5	82.5
8	Wheat-Straw	85.0	76.9	83.6	78.0	80.9	81.3
9	Mixed Mineral Manure, and 400 lbs. each, Sulphate and Muriate Ammonia	85.0	76.9	83.6	78.0	80.9	81.3
10	Mixed Mineral Manure, including 200 lbs. each, Silicates Soda, and Lime, and 400 lbs. each, Sulphate and Muriate Ammonia	84.4	78.6	84.5	78.4	81.7	82.72
11	Mixed Mineral Manure, and 275 lbs. Nitrate of Soda	85.0	80.3	84.7	79.4	82.4	82.72
12	Mixed Mineral Manure, and 500 lbs. Nitrate of Soda	85.0	80.3	84.7	79.4	82.4	82.72
	Mean	85.9	79.7	84.0	78.7	82.1	82.5
SERIES 3.—With Farmyard Manure.							
16	14 tons Farmyard Manure	88.2	82.7	84.6	77.9	83.4	83.0
17	14 tons Farmyard Manure, and 100 lbs. each, Sulphate and Muriate Ammonia	87.3	81.2	84.3	78.4	82.8	82.8
* With Sulphate of Potash excluded, and the amount of Sulphate of Soda increased, in 1862.							
† Only 200 lbs. each in 1859, 1860, and 1861.							
‡ Average of 5 years only.							

EXPERIMENTS at ROTHAMSTED with DIFFERENT MANURES on PERMANENT MEADOW LAND.

TABLE IV.—PERCENTAGES of MINERAL MATTER (Ash) in the HAY (Means of Duplicate Determinations).

Plot No.	MANURES PER ACRE, PER ANNUM (For detailed description, see pp. 3, 4.)	Percentages in the Hay as taken from the Land.					Percentages in the Dry Substance of the Hay.				
		1859. Cut June 27; July 5.	1860. Cut July 7; July 13.	1861. Cut June 27; July 5.	1862. Cut June 27; July 5.	Average. Of 4 Years (1859-62).	1859. Cut June 27; July 5.	1860. Cut July 7; July 13.	1861. Cut June 27; July 5.	1862. Cut June 27; July 5.	Average. Of 4 Years (1859-62).

SERIES 1.—Without Direct Mineral Manure.											
1	Unmanured (duplicate plot)	6.38	6.37	5.77	6.12	6.12	6.01	7.57	6.76	7.80	7.16
2	Unmanured	6.34	6.16	5.94	5.48	5.98	5.98	7.33	6.89	7.10	7.08
3	Mean, or Standard Unmanured	6.33	6.08	5.81	5.80	5.99	5.96	7.34	6.85	7.35	7.18
4	200 lbs. each, Sulphate and Murate Ammonia	5.48	5.23	5.19	5.38	5.34	5.49	6.48	6.53	6.78	6.64
5	200 lbs. each, Sulph. & Mur. Ammonia, & 200 lbs. Sawdust	5.56	5.24	5.01	5.16	5.34	5.40	6.35	6.52	6.57	6.51
6	200 lbs. each, Sulphate of Soda	6.00	6.08	5.69	7.11	6.22	6.12	7.06	6.73	9.08	7.42
7	500 lbs. Nitrate of Soda	5.84	6.08	5.70	6.43	6.01	5.86	6.98	6.71	8.28	7.12
	Mean.	5.84	5.74	5.48	5.97	5.76	5.77	6.81	6.51	7.60	6.98

SERIES 2.—With Direct Mineral Manure.											
35	Superphosphate of Lime	6.29	6.68	6.38	6.40	6.68	..	7.48	6.22	7.80	6.00
36	Superphosphate of Lime, and 200 lbs. each, Sulphate and Murate Ammonia	6.28	6.30	5.54	5.34	5.67	..	7.27	7.85	6.61	6.99
8	Mixed Mineral Manure	7.16	6.92	6.28	6.90	6.79	6.67	8.17	8.66	7.41	8.67
9	Mixed Mineral Manure, and 200 lbs. Sawdust	7.08	6.60	6.06	6.54	6.70	6.74	8.08	8.24	7.85	8.03
10	Murate Ammonia, and 200 lbs. each, Sulphate and Murate Ammonia	6.43	6.34	6.06	6.08	6.23	6.38	7.75	7.80	7.26	7.63
11	Mixed Mineral Manure, 200 lbs. each, Sulphate and Murate Ammonia, and 200 lbs. Sawdust	6.99	6.85	6.48	5.92	6.56	6.63	8.21	8.68	7.67	8.10
12	Mixed Mineral Manure, 200 lbs. each, Sulphate and Murate Ammonia, and 200 lbs. Cut Wheat-Straw	6.94	6.40	6.68	5.98	6.50	6.56	7.98	8.17	7.98	7.95
13	Mixed Mineral Manure, and 400 lbs. each, Sulphate and Murate Ammonia	6.61	5.56	6.30	6.40	6.22	6.28	7.77	7.53	7.54	7.79
135	Mixed Mineral Manure, (including 200 lbs. each, Sulphate of Soda, and Lime), and 400 lbs. each, Sulphate and Murate Ammonia	..	..	..	6.55	..	..	..	..	8.36	..
14	Mixed Mineral Manure, and 2.5 lbs. Nitrate of Soda	6.65	6.85	6.48	6.94	6.73	6.65	7.68	7.67	8.73	8.05
15	Mixed Mineral Manure, and 200 lbs. Nitrate of Soda	6.26	6.94	6.09	6.60	6.34	6.30	7.35	7.53	7.30	7.61
	Mean	6.73	6.45	6.30	6.32	6.45	6.53	7.85	8.10	7.50	7.96

SERIES 3.—With Farmyard Manure.											
16	14 tons Farmyard Manure	6.95	6.74	6.78	7.27	6.94	6.89	7.68	8.16	8.02	8.34
17	14 tons Farmyard Manure, and 100 lbs. each, Sulphate and Murate Ammonia	6.76	6.61	6.30	6.96	6.76	6.58	7.74	8.36	7.71	8.26

* With Sulphate of Potash excluded, and the amount of Sulphate of Soda increased, in 1862. † Only 200 lbs. each in 1860, 1861, and 1862. ‡ Average of 5 years only.

EXPERIMENTS at ROTHAMSTON with DIFFERENT MANURES on PERMANENT MEADOW LAND.

TABLE V.—PERCENTAGES of NITROGEN in the HAY (Means of Duplicate Determinations).

Plot, Nos.	MANURES PER ACRE, PER ANNUM. (For detailed description, see pp. 3-4.)	Percentages in the Hay as taken from the Land.					Percentages in the Dry Substance of the Hay.																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																								
		Average.			1899.		Average.			1899.																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																					
		Cut June 7; carried July 4.	Cut June 28; carried July 4.	Cut June 28; carried July 4.	Cut June 7; carried July 4.	Cut June 28; carried July 4.	Cut June 7; carried July 4.	Cut June 28; carried July 4.	Cut June 7; carried July 4.	Cut June 28; carried July 4.	Cut June 7; carried July 4.																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																				
		1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1899.	1

SERIES 1.—Without Direct Mineral Manure.

1	Unmanured (duplicate plot)	1'50	1'36	1'31	1'19	1'24	1'39	1'69	1'64	1'53	1'55	1'60	1'67	1'75
2	Unmanured	1'50	1'45	1'39	1'29	1'37	1'44	1'74	1'82	1'63	1'57	1'60	1'67	1'75
3	Mean, or Standard Unmanured	1'50	1'41	1'30	1'22	1'36	1'41	1'73	1'73	1'53	1'55	1'63	1'63	1'69
4	200 lbs. each, Sulphate and Muriate Ammonia	1'74	1'64	1'71	1'71	1'75	1'68	2'03	2'05	2'01	2'06	2'13	2'13	2'08
5	200 lbs. each, Sulphate and Muriate Ammonia, and 2000 lbs. Sawdust.	1'68	1'61	1'67	1'47	1'63	1'60	1'68	2'10	1'87	1'87	1'98	1'98	1'98
6	275 lbs. Nitrate of Soda.	1'58	1'58	1'49	1'50	1'48	1'47	1'76	1'74	1'67	1'66	1'73	1'73	1'75
7	500 lbs. Nitrate of Soda.	1'59	1'58	1'56	1'45	1'53	1'52	1'90	1'89	1'86	1'87	1'88	1'88	1'91
	Mean	1'63	1'57	1'54	1'43	1'54	1'55	1'89	1'94	1'88	1'88	1'97	1'97	1'87

SERIES 2.—With Direct Mineral Manure.

32	Superphosphate of Lime	1'59	1'37	1'39	1'23	1'39	1'39	1'81	1'68	1'66	1'54	1'67	1'67	..
33	Superphosphate of Lime, and 200 lbs. each, Sulphate and Muriate Ammonia	1'41	1'43	1'49	1'38	1'43	1'43	1'63	1'79	1'77	1'78	1'74	1'74	..
8	Muriate Ammonia	1'57	1'49	1'59	1'31	1'48	1'48	1'79	1'86	1'81	1'87	1'71	1'71	1'75
9	"Mixed Mineral Manure"*, and 200 lbs. each, Sulphate and Muriate Ammonia	1'60	1'54	1'54	1'27	1'44	1'49	1'63	1'88	1'89	1'89	1'73	1'73	1'75
10	"Mixed Mineral Manure", and 200 lbs. each, Sulphate and Muriate Ammonia	1'18	1'21	1'38	1'15	1'23	1'23	1'43	1'49	1'65	1'45	1'51	1'51	1'49
11	"Mixed Mineral Manure"*, 200 lbs. each, Sulphate and Muriate Ammonia, and 2000 lbs. Sawdust	1'19	1'20	1'19	1'16	1'17	1'17	1'38	1'52	1'49	1'48	1'44	1'44	1'44
12	"Mixed Mineral Manure", 200 lbs. each, Sulphate and Muriate Ammonia, and 2000 lbs. Sawdust	1'28	1'28	1'33	1'09	1'21	1'28	1'40	1'53	1'58	1'36	1'47	1'47	1'56
12a	"Mixed Mineral Manure", 200 lbs. each, Sulphate and Muriate Ammonia, and 400 lbs. each, Sulphate and Muriate Ammonia	1'29	1'19	1'23	1'41	1'28	1'48	1'52	1'55	1'47	1'81	1'59	1'59	1'75
12b	"Mixed Mineral Manure" (including 200 lbs. each, Sulphate and Muriate Ammonia, and 275 lbs. Nitrate of Soda, and 275 lbs. Nitrate of Soda)	..	..	..	1'41	..	..	..	..	..	1'79	..	..	..
14	"Mixed Mineral Manure", and 275 lbs. Nitrate of Soda	1'42	1'50	1'59	1'13	1'29	1'29	1'69	1'66	1'60	1'48	1'57	1'57	1'61
15	"Mixed Mineral Manure", and 500 lbs. Nitrate of Soda	1'21	1'17	1'18	1'13	1'17	1'17	1'20	1'45	1'39	1'43	1'43	1'43	1'42
	Mean	1'28	1'31	1'31	1'34	1'30	1'38	1'59	1'65	1'55	1'57	1'59	1'59	1'61

SERIES 3.—With Farmyard Manure.

16	14 tons Farmyard Manure	1'20	1'19	1'36	1'10	1'19	1'23	1'36	1'44	1'46	1'41	1'43	1'43	1'49
17	14 tons Farmyard Manure, and 100 lbs. each, Sulphate and Muriate Ammonia	1'17	1'30	1'23	1'19	1'18	1'24	1'34	1'48	1'45	1'43	1'43	1'43	1'50

* With Sulphate of Potash excluded, and the amount of Sulphate of Soda increased, in 1899.

† Only 200 lbs. each in 1899, 1900, and 1901.

‡ Average of 5 years only.

EXPERIMENTS at ROTHAMSTED with DIFFERENT MANURES on PERMANENT MEADOW LAND.

TABLE VI.—PRODUCE OF TOTAL DRY SUBSTANCE per Acre; lbs.

Plot, No.	MANURES PER ACRE, PER ANNUM. (For detailed description, see pp. 3-4.)	Annual Produce.			Average Annual Increase by Manure.		
		1889.	1890.	1891.	Average.		
					Of 4 Years (1889-92).	Of 7 Years (1886-92).	Of 7 Years (1890-96).
		1889.	1890.	1891.	1862.		

SERIES 1.—Without Direct Mineral Manure.

[illegible]

SERIES 2.—With Direct Mineral Manure.

36	Superphosphate of Lime	5479½	2599	2841	2509½	2614½	199½	..
37	Superphosphate of Limes, and 200 lbs. each, Sulphate and Muriate Ammonia	4317½	3944½	4169½	3699½	4004	1801½	..
38	"Mixed Mineral Manure" *, and 2000 lbs. Sawdust	3999½	3140	3802½	3471½	3899	999½	909½
9	"Mixed Mineral Manure" *, and 2000 lbs. Sawdust	3975	3599½	3870½	3599½	3854	1013	1009
10	"Mixed Mineral Manure" *, and 200 lbs. each, Sulphate and Muriate Ammonia	5140½	4599½	5375½	5007½	5394½	2567½	9999½
11	"Mixed Mineral Manure" *, 300 lbs. each, Sulphate and Muriate Ammonia, and 2000 lbs. Sawdust	4999	4299½	5399½	4999½	4999	2499½	3747½
12	"Mixed Mineral Manure", 300 lbs. each, Sulphate and Muriate Ammonia, and 2000 lbs. Chit Wheat Straw	6099½	4510½	5499½	4909½	5099½	2909	3737
132	"Mixed Mineral Manure", and 400 lbs. each, Sulphate and Muriate Ammonia	6099½	4119½	5009½	5549½	5419	2999½	3899½
130	"Mixed Mineral Manure", (including 300 lbs. each, Silicate Soda, and Lime), and 400 lbs. Chit Wheat Straw	..	..	..	5599½	..	..	..
14	"Mixed Mineral Manure", and 270 lbs. Nitrate of Soda	4191½	3799½	4997	4119½	4199½	1799½	1799½
15	"Mixed Mineral Manure", and 500 lbs. Nitrate of Soda	5193	4497½	4999½	4599½	4799½	2379	9499½

SERIES 3.—With Farmyard Manure.

16	14 tons Farnyard Manure	4037	4375	2008	4103	3973	1790
17	14 tons Farnyard Manure, and 100 lbs. each Sulphate and Muriate Ammonia.	4694	4467	3363	4375	431	2115
							1614
							2179

• With Sulphate of Potass excluded, and the amount of Sulphate of Soda increased, in 1892.

† Only 200 lbs, each in 1859, 1860, and 1861.

† Average of 5 years only.

EXPERIMENTS at BOTHAMSTED with DIFFERENT MANURES ON PERMANENT MEADOW LAND.

TABLE VII.—PRODUCE OF TOTAL MINERAL MATTER (Ash) per Acre; lb.

Plot, Nos.	MANURES PER ACRE, PER ANNUM. (For detailed description, see pp. 3-4.)	Annual Produce.					Average Annual Increase by Manure.		
		1859.		1860.		Average.	Of		Of
							4 Years (1859-63)	7 Years (1859-65)	

SERIES 1.—Without Direct Mineral Manure.

		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1	Unmanured (duplicate plot)	160.5	164.2	166.9	171.3	168.2	167.5	167.5	167.5
2	Unmanured (duplicate plot)	160.5	164.2	166.9	171.3	168.2	167.5	167.5	167.5
3	Unmanured (duplicate plot)	160.5	164.2	166.9	171.3	168.2	167.5	167.5	167.5
4	200 lbs. each, Sulphate and Muriate Ammonia	161.9	178.5	187.3	174.3	180.2	180.2	180.2	180.2
5	200 lbs. each, Sulphate and Muriate Ammonia, and 200 lbs. Sawdust	199.7	197.5	206.6	190.2	204.5	204.5	204.5	204.5
6	200 lbs. Nitrate of Soda	203.1	227.3	232.9	237.7	235.0	237.7	237.7	237.7
7	500 lbs. Nitrate of Soda	240.4	267.2	283.9	285.9	285.9	283.12	283.12	283.12

SERIES 2.—With Direct Mineral Manure.

		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
34	Superphosphate of Lime	194.9	211.7	206.0	209.2	206.7	209.2	209.2	209.2
35	Superphosphate of Lime	313.7	275.4	253.8	286.2	281.0	281.0	281.0	281.0
36	Superphosphate of Lime	344.6	321.8	301.9	321.9	311.9	311.9	311.9	311.9
9	Mixed Mineral Manure, and 200 lbs. Sawdust	344.6	321.8	301.9	321.9	311.9	311.9	311.9	311.9
10	Mixed Mineral Manure, and 200 lbs. each, Sulphate and Muriate Ammonia	386.4	385.0	359.2	381.7	404.3	397.4	397.4	397.4
11	Mixed Mineral Manure, and 200 lbs. each, Sulphate and Muriate Ammonia, and 2000 lbs. Sawdust	409.2	413.2	385.6	388.8	413.0	413.0	413.0	413.0
12	Mixed Mineral Manure, and 200 lbs. each, Sulphate and Muriate Ammonia, and 2000 lbs. Sawdust	494.1	438.9	368.4	413.8	464.7	438.9	438.9	438.9
13	Mixed Mineral Manure, and 400 lbs. each, Sulphate and Muriate Ammonia	473.5	423.7	454.9	417.4	458.6	458.6	458.6	458.6
13a	Mixed Mineral Manure, and 400 lbs. each, Sulphate and Muriate Ammonia	473.5	423.7	454.9	417.4	458.6	458.6	458.6	458.6
13b	Mixed Mineral Manure, and 400 lbs. each, Sulphate and Muriate Ammonia	473.5	423.7	454.9	417.4	458.6	458.6	458.6	458.6
14	Mixed Mineral Manure, and 275 lbs. Nitrate of Soda	389.5	387.3	359.1	343.9	389.5	389.5	389.5	389.5
15	Mixed Mineral Manure, and 550 lbs. Nitrate of Soda	379.9	358.9	377.4	363.4	363.4	363.4	363.4	363.4

SERIES 3.—With Farmyard Manure.

		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
16	14 tons Farmyard Manure	318.3	348.7	369.0	345.1	389.7	370.8	370.8	370.8
17	14 tons Farmyard Manure, and 100 lbs. each, Sulphate and Muriate Ammonia	331.9	348.0	368.7	370.8	379.2	379.2	379.2	379.2

* With Sulphate of Potash excluded, and the amount of Sulphate of Soda increased, in 1862. † Only 200 lbs. each in 1859, 1860, and 1861. ‡ Average of 5 years only.

EXPERIMENTS at ROTHAMSTED with DIFFERENT MANURES on PERMANENT MEADOW LAND.

TABLE VI.—PRODUCE of TOTAL DRY SUBSTANCE per Acre; lbs.

Plot, Nos.	MANURES PER ACRE, PER ANNUM. (For detailed description, see pp.3-4.)	Annual Produce.					Average Annual Increase by Manure.		
		1859.	1860.	1861.	1862.	Average.			
						Of 4 Years (1859-62).	Of 7 Years (1860-62).	Of 7 Years (1859-65).	

SERIES 1.—Without Direct Mineral Manure.

Plot, Nos.	Manures	1859.	1860.	1861.	1862.	Of 4 Years (1859-60).	Of 7 Years (1859-62).	Of 7 Years (1859-65).
1	Unmanured (duplicate plot):	2228	2297½	2777	2728½	2604½	2684½	..
2	Unmanured	2228	2297½	2777	2728½	2604½	2684½	..
4	300 lbs. each, Sulphate and Muriate Ammonia	2287	3298½	2801½	3258½	2489½	2536½	728½
5	300 lbs. each, Sulphate and Muriate Ammonia, and 3000 lbs. Sawdust	3104	3400½	3264½	3045	3261½	3081	609
6	275 lbs. Nitrate of Soda	2210½	3400½	3264½	3264½	3099	3184½	676½
7	550 lbs. Nitrate of Soda	2444½	3130	3485	3264½	3264½	3130	884½
		3444½	3477½	3783½	3168½	3473½	3304½	1082½

SERIES 2.—With Direct Mineral Manure.

Plot, Nos.	Manures	1859.	1860.	1861.	1862.	Of 4 Years (1859-60).	Of 7 Years (1859-62).	Of 7 Years (1859-65).
34	Superphosphate of Lime	2478½	2841	2841	2563½	2614½	..	1594½
35	Superphosphate of Lime, and 300 lbs. each, Sulphate and Muriate Ammonia	4317½	3846½	4169½	3698½	4004	..	1581½
8	"Mixed Mineral Manure"	2994½	3140	3804½	3471½	3364½	2899	999½
9	"Mixed Mineral Manure," and 300 lbs. Sawdust	2575	3264½	3670½	3404½	3404½	2410½	1013
10	"Mixed Mineral Manure," and 300 lbs. each, Sulphate and Muriate Ammonia	5104	4568½	3873½	3671½	5010	5264½	2567½
11	"Mixed Mineral Manure," 300 lbs. each, Sulphate and Muriate Ammonia, and 3000 lbs. Sawdust	4896	4399½	4894½	4894½	4696	5106	2484½
13	"Mixed Mineral Manure," 300 lbs. each, Sulphate and Muriate Ammonia, and 3000 lbs. Cut Wheat-Straw	6084	4510½	5493½	4904½	5301½	5064½	2908½
12a	"Mixed Mineral Manure," and 400 lbs. each, Sulphate and Muriate Ammonia	6084	4418½	5004½	5543½	5413	5684½	2894
13b	"Mixed Mineral Manure," (including 300 lbs. each, Sulphate of Soda, and Lime), and 400 lbs. Cut Wheat-Straw	6084	4418½	5004½	5543½	5413	5684½	2894
14	"Mixed Mineral Manure," and 275 lbs. Nitrate of Soda	4181½	3794½	4597	4119½	4198½	4079½	1790½
15	"Mixed Mineral Manure," and 550 lbs. Nitrate of Soda	5163	4487½	4984½	4539½	4794½	4796½	2439½

SERIES 3.—With Farnyard Manure.

Plot, Nos.	Manures	1859.	1860.	1861.	1862.	Of 4 Years (1859-60).	Of 7 Years (1859-62).	Of 7 Years (1859-65).
16	14 tons Farnyard Manure	4043½	4307	4375	3643½	4194½	3973	1614½
17	14 tons Farnyard Manure, and 100 lbs. each Sulphate and Muriate Ammonia	4678	4694	4487	4384½	4571½	4431	2178½

* With Sulphate of Potash excluded, and the amount of Sulphate of Soda increased, in 1862.

† Only 300 lbs. each in 1860, and 1861.

‡ Average of 5 years only.

EXPERIMENTS at ROTHAMSTED with DIFFERENT MANURES ON PERMANENT MEADOW LAND.
TABLE VII.—PRODUCE OF TOTAL MINERAL MATTER (Ash) per Acre; lbs.

Plot Nos.	MANURES PER ACRE, PER ANNUM. (For detailed description, see pp. 3-4.)	Annual Produce.				Average Annual Increase by Manure.			
		1860.		1861.		1862.			
		1859.	1860.	1861.	1862.	Of 4 Years (1859-62)	Of 7 Years (1856-62)		
SERIES 1.—Without Direct Mineral Manure.									
1	Unmanured (duplicate plot)	lbs. 180.5	lbs. 173.1	lbs. 164.3	lbs. 186.9	177.4	171.5	lbs.	lbs.
2	Unmanured	180.5	166.0	162.8	187.6	177.4	165.4	..	..
3	Unmanured	180.5	166.0	162.8	187.6	177.4	165.4	..	..
4	200 lbs. each, Sulphate and Muriate Ammonia	181.9	169.6	179.5	187.3	174.3	167.5	16.9	37.0
5	200 lbs. each, Sulphate and Muriate Ammonia, and 2000 lbs. Sawdust	199.7	156.8	177.6	206.6	180.2	204.3	23.6	40.3
6	200 lbs. Nitrate of Soda	213.1	239.2	238.9	216.0	240.8	234.32	76.5	67.02
7	500 lbs. Nitrate of Soda	240.4	287.2	283.9	283.2	283.9	284.12	81.0	75.62
SERIES 2.—With Direct Mineral Manure.									
3a	Superphosphate of Lime	184.9	212.2	221.7	208.0	209.2	..	34.9	..
3b	Superphosphate of Lime, and 200 lbs. Sulphate and Muriate Ammonia	313.7	301.6	275.4	253.8	286.3	..	111.9	..
8	Mixed Mineral Manure	223.0	273.0	281.8	259.9	274.9	261.0	100.0	107.5
9	Mixed Mineral Manure, and 2000 lbs. Sawdust	253.8	249.0	303.8	259.9	277.1	275.2	102.8	107.7
10	Mixed Mineral Manure, and 200 lbs. each, Sulphate and Muriate Ammonia	388.4	286.3	385.0	339.2	381.7	404.3	207.4	236.8
11	Mixed Mineral Manure, 200 lbs. each, Sulphate and Muriate Ammonia, and 2000 lbs. Sawdust	409.2	287.2	413.2	385.6	388.8	412.0	214.5	244.5
12	Mixed Mineral Manure, 200 lbs. each, Sulphate and Muriate Ammonia, and 2000 lbs. "Cut Wheat-Straw"	484.1	388.6	438.9	388.4	413.8	404.7	239.5	287.2
13a	Mixed Mineral Manure, and 400 lbs. each, Sulphate and Muriate Ammonia	473.5	319.4	423.7	454.9	417.4	435.6	243.1	266.1
13b	Mixed Mineral Manure, (including 200 lbs. each, Silicates Soda, and Lime), and 400 lbs. each, Sulphate and Muriate Ammonia	..	..	..	466.5	..	..	..	..
14	Mixed Mineral Manure, and 275 lbs. Nitrate of Soda	389.5	389.5	387.3	359.1	343.9	389.32	169.6	161.62
15	Mixed Mineral Manure, and 500 lbs. Nitrate of Soda	379.9	337.4	338.9	377.4	363.4	364.32	169.1	186.32
SERIES 3.—With Farmyard Manure.									
16	14 tons Farmyard Manure	318.3	331.2	249.7	288.0	245.1	288.7	170.8	161.2
17	14 tons Farmyard Manure, and 100 lbs. each, Sulphate and Muriate Ammonia	381.9	388.6	346.0	386.7	370.6	372.2	186.5	204.7

* With Sulphate of Potash exchanged, and the amount of Sulphate of Soda increased, in 1862.
† Only 900 lbs. each in 1859, 1860, and 1861.
‡ Average of 5 years only.

* With Sulphate of Potash excluded, and the amount of Sulphate of Soda increased, in 1862. † Only 200 lbs. each in 1859, 1860, and 1861. ‡ Average of 5 years only.

EXPERIMENTS at ROTHAMSTED with DIFFERENT MANURES on PERMANENT MEADOW LAND.

TABLE VIII.—PRODUCE OF NITROGEN per ACRE; lbs.

Plot Nos.	MANURES PER ACRE, PER ANNUM. (For detailed description, see pp. 3-4)	Annual Produce.					Average Annual Increase by Manure.	
		1869.	1860.	1861.	1862.	Average.	Of 4 Years (1859-62).	Of 7 Years (1856-62).

SERIES 1.—Without Direct Mineral Manure.

		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1	Unmanured (duplicate plot).	38.1	37.5	37.3	36.3	37.3	37.6	37.3
2	Unmanured (duplicate plot).	38.6	41.8	45.6	46.9	45.5	45.2	45.2
4	Mean, or Standard Unmanured	38.4	39.7	38.9	41.5	39.9	39.9	39.9
5	200 lbs. each, Sulphate and Muriate Ammonia	63.4	54.1	65.1	65.9	68.1	68.3	68.3
6	200 lbs. each, Sulphate and Muriate Ammonia, and 2000 lbs. Sawdust	61.6	50.7	65.9	65.4	60.9	60.9	60.9
7	275 lbs. Nitrate of Soda.	56.7	54.5	58.1	57.8	56.8	56.32	56.32
	550 lbs. Nitrate of Soda.	65.4	66.2	70.3	59.2	65.3	64.41	64.41

SERIES 2.—With Direct Mineral Manure.

		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
3a	Superphosphate of Lime	45.0	43.5	47.3	39.7	48.9	4.0	4.0
3b	Superphosphate of Lime, and 200 lbs. each, Sulphate and Muriate Ammonia	70.4	66.5	74.0	65.6	69.6	29.7	29.7
8	"Mixed Mineral Manure," including 200 lbs. each, Silicates Soda, and Lime, and 2000 lbs. Sawdust	53.6	58.5	57.9	58.0	57.0	17.1	16.9
9	"Mixed Mineral Manure," and 800 lbs. each, Sulphate and Muriate Ammonia	54.3	63.6	61.7	57.5	59.3	19.4	20.5
10	"Mixed Mineral Manure," and 800 lbs. each, Sulphate and Muriate Ammonia, and 2000 lbs. Sawdust	73.1	68.1	73.6	77.3	75.5	35.6	38.0
11	"Mixed Mineral Manure," 200 lbs. each, Sulphate and Muriate Ammonia, and 2000 lbs. Sawdust	65.5	64.3	76.5	71.7	69.5	29.6	33.0
12	"Mixed Mineral Manure," 800 lbs. each, Sulphate and Muriate Ammonia, and 2000 lbs. Sawdust	88.1	70.2	88.7	100.2	77.0	37.1	39.2
13a	"Mixed Mineral Manure," and 400 lbs. each, Sulphate and Muriate Ammonia	92.2	68.4	88.5	100.2	86.8	45.9	56.4
13b	400 lbs. each, Sulphate and Muriate Ammonia	..	..	100.4	100.4	..	..	..
14	"Mixed Mineral Manure," and 275 lbs. Nitrate of Soda	70.4	68.6	70.6	59.3	65.5	25.6	25.6
15	"Mixed Mineral Manure," and 550 lbs. Nitrate of Soda	73.5	63.4	68.5	64.6	65.5	28.4	29.62

SERIES 3.—With Farmyard Manure.

		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
14	14 tons Farmyard Manure	55.0	63.0	63.7	53.7	59.1	56.5	19.2
17	14 tons Farmyard Manure, and 100 lbs. each, Sulphate and Muriate Ammonia	66.7	68.4	66.4	68.3	64.7	67.5	27.6

* With Sulphate of Potash excluded, and the amount of Sulphate of Soda increased, in 1862.

† Only 200 lbs. each in 1860, 1861, and 1862.

‡ Average of 5 years only.

EXPERIMENTS at ROTHAMSTED with DIFFERENT MANURES on PERMANENT MEADOW LAND.

TABLE IX.—INCREASED YIELD OF NITROGEN PER ACRE when a known Quantity was supplied in MANURE; lbs.

Plot, No.	MANURES PER ACRE, PER ANNUM. (For detailed description, see pp. 3-4.)	Increase over the yield without Manure.					Increase over the yield by the "Mixed Mineral Manure."				
		1859. 1860. 1861. 1862.			Average	1859. 1860. 1861. 1862.			Average		
		Of 4 Years (1859-62.)	Of 7 Years (1859-62.)	Of 7 Years (1859-62.)	Of 4 Years (1859-62.)	Of 7 Years (1859-62.)	Of 4 Years (1859-62.)	Of 7 Years (1859-62.)			
SERIES 1.—Without Direct Mineral Manure.											
4	200 lbs. each, Sulphate and Muriate Ammonia	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
5	200 lbs. each, Sulphate and Muriate Ammonia, and 2000 lbs. Soda	25.0	14.4	25.2	23.2	25.4	..	..	..	..	..
6	200 lbs. each, Sulphate and Muriate Ammonia, and 2000 lbs. Soda	23.2	11.0	23.8	21.0	21.1	..	..	..	..	..
7	200 lbs. Nitrate of Soda	18.3	14.8	18.2	16.2	16.9	..	..	..	..	..
7	500 lbs. Nitrate of Soda	27.1	26.5	30.4	17.6	24.5	..	..	..	..	..
SERIES 2.—With Direct Mineral Manure.											
26	Superphosphate of Lime, and 200 lbs. each, Sulphate and Muriate Ammonia	38.1	28.8	34.1	24.0	29.8	..	16.8	10.0	16.1	19.6
10	" Mixed Mineral Manure," and 200 lbs. each, Sulphate and Muriate Ammonia	34.8	26.4	27.2	23.0	25.6	28.1	19.5	9.6	29.3	15.6
11	" Mixed Mineral Manure," and 200 lbs. each, Sulphate and Muriate Ammonia	27.2	24.7	26.6	20.1	29.7	33.1	11.9	5.8	16.6	13.7
12	" Mixed Mineral Manure," and 200 lbs. each, Sulphate and Muriate Ammonia, and 2000 lbs. Cut Wheat-Straw	46.7	30.5	45.8	25.3	37.1	29.2	31.5	11.7	27.8	9.1
13a	" Mixed Mineral Manure," and 400 lbs. each, Sulphate and Muriate Ammonia	35.9	26.7	29.6	25.6	46.0	36.4	28.6	9.9	24.6	28.8
13b	" Mixed Mineral Manure," (including 200 lbs. each, Silicates of Soda, and Lime), and 400 lbs. each, Sulphate and Muriate Ammonia	..	..	..	..	..	..	..	..	..	..
14	" Mixed Mineral Manure," and 275 lbs. Nitrate of Soda	23.0	22.9	20.6	16.9	25.6	25.4	16.8	4.1	19.7	8.5
15	" Mixed Mineral Manure," and 500 lbs. Nitrate of Soda	25.1	25.7	29.6	23.0	28.4	28.6	19.9	6.9	11.6	11.3
SERIES 3.—With Farnyard Manure. §											
17	14 tons Farnyard Manure, and 100 lbs. each, Sulphate and Muriate Ammonia	7.7	6.5	1.8	6.6	5.7	9.0	..	..	..	..

EXPERIMENTS at ROTHAMSTED with DIFFERENT MANURES on PERMANENT MEADOW LAND.
TABLE X.—NITROGEN recovered, and not recovered, as increased yield of it, for 100 supplied in MANURE.

MANURES PER ACRE, PER ANNUM. (For detailed description, see pp 3-4.)		Increase taken over the yield without Manure.					Increase taken over the yield by the "Mixed Mineral Manure."				
		Per Cent. of supplied Nitrogen recovered as Increase.					Per Cent. of supplied Nitrogen recovered as Increase.				
		Average					Average				
		Of 4 Years (1859-62).	Of 7 Years (1863-65).	Of 4 Years (1859-62).	Of 7 Years (1863-65).	Of 4 Years (1859-62).	Of 4 Years (1859-62).	Of 7 Years (1863-65).	Of 4 Years (1859-62).	Of 7 Years (1863-65).	Average per Cent. of supplied Nitrogen not recovered as Increase.
SERIES 1.—Without Direct Mineral Manure.											
4	200 lbs. each, Sulphate and Muriate Ammonia	30.5	17.6	30.7	29.6	27.1	27.4	72.9	72.6	..	..
5	200 lbs. each, Sulphate & Muriate Ammonia, and 900 lbs. Sawdust	26.8	19.7	30.1	27.5	24.3	24.4	75.7	75.6	..	..
6	275 lbs. Nitrate of Soda	44.6	38.1	44.4	39.5	41.2	37.7	58.8	63.3	..	..
7	350 lbs. Nitrate of Soda	53.1	38.3	57.1	31.5	31.0	29.9	69.0	70.1	..	..
	Mean	33.8	34.7	35.6	29.5	30.9	29.9	69.1	70.1	..	..
SERIES 2.—With Direct Mineral Manure.											
26	Superphosphate of Lime, and 200 lbs. each, Sulphate and Muriate Ammonia	39.1	35.1	41.6	29.3	26.3	..	63.7	..	..	..
10	"Mixed Mineral Manure," and 200 lbs. each, Sulphate and Muriate Ammonia	42.4	34.6	37.6	39.0	43.4	46.5	56.6	53.5	23.8	74.3
11	"Mixed Mineral Manure," and 200 lbs. each, Sulphate and Muriate Ammonia, and 800 lbs. Sawdust	31.5	28.6	43.3	34.8	34.3	38.2	65.7	61.8	13.8	81.4
12	"Mixed Mineral Manure," and 200 lbs. each, Sulphate and Muriate Ammonia, and 900 lbs. Cut Wheat-Straw	49.4	32.2	46.4	27.0	26.2	41.4	60.8	58.6	33.3	76.4
13a	"Mixed Mineral Manure," and 400 lbs. each, Sulphate and Muriate Ammonia	65.7	35.0	52.0	35.7	47.1	46.5	53.9	53.5	47.1	68.4
13b	"Mixed Mineral Manure," (including 200 lbs. each, Sulphate and Soda, and 400 lbs. each, Sulphate and Muriate Ammonia)	..	..	..	33.9	..	..	..	..	25.9	..
14	"Mixed Mineral Manure," and 200 lbs. Nitrate of Soda	78.1	55.9	74.6	41.2	63.4	61.9	37.6	33.1	41.0	79.3
15	"Mixed Mineral Manure," and 500 lbs. Nitrate of Soda	43.8	31.3	38.1	28.1	34.6	36.1	65.4	63.9	24.3	84.8
	Mean	49.9	36.1	50.4	33.9	43.5	45.1	57.5	54.9	29.1	77.4
SERIES 3.—With Farmyard Manure.											
17	14 tons Farmyard Manure, and 200 lbs. each, Sulphate and Muriate Ammonia	18.8	15.9	4.4	16.1	19.8	21.9	86.3	76.1	..	..
	Mean	..	..	..	..	..	..	..	..	..	..

• With Sulphate of Potash excluded, and the amount of Sulphate of Soda increased, in 1863.

† State on the south side, from east-west.

* With Sulphate of Potash excluded, and the amount of Sulphate of Soda increased, in 1866.

† Excludes the results of 1866. See note page 10.

LONDON :
Printed by W. Clowes and Sons, Stamford Street,
and Charing Cross.



REPORT OF EXPERIMENTS
ON THE
GROWTH OF WHEAT
FOR TWENTY YEARS
IN SUCCESSION ON THE SAME LAND.

BY
J. B. LAWES, F.R.S., F.C.S., & J. H. GILBERT, Ph.D., F.R.S., F.C.S.

LONDON:
PRINTED BY W. CLOWES AND SONS, STAMFORD STREET,
AND CHARING CROSS.

1864.

FROM THE
JOURNAL OF THE ROYAL AGRICULTURAL SOCIETY OF ENGLAND,
VOL. XXV. PARTS I. & II.

CONTENTS.

	Page
Introductory observations, statement of the question, and historical notice	5
Objects and general plan of the experiments	8

THE FIELD EXPERIMENTS AND RESULTS.

Scope and extent of the experimental results, and limitation of the record and discussion in the present report	11
General description of the manures employed	12
Division of the subject	15

I.—AMOUNT AND CHARACTER OF THE PRODUCE OBTAINED IN DIFFERENT SEASONS.

Characters of the season, and amount and characters of the produce, of each of the first eight years; harvests 1844-1851 inclusive ..	15
Plan and description of the manuring for the ninth and eleven succeeding seasons, 1851-2 to 1862-3 inclusive	29
Characters of the season, and amount and characters of the produce, of the ninth and each of the eleven succeeding years; harvests 1852-1863 inclusive	31
Comparison of the produce of the least and the most favourable seasons of the twenty; harvests 1853 and 1863	51
Comparison of the productiveness of the earlier and the later seasons of the experiments	53

II.—EFFECTS OF THE UNEXHAUSTED RESIDUE FROM PREVIOUS MANURING UPON SUCCEEDING CROPS.

Importance and difficulties of the subject	57
Effects of the unexhausted residue from previous nitrogenous manuring, and collateral points	57
Effects of the unexhausted residue from previous mineral manuring; effects of a given amount of ammonia salts according to the available supply of mineral constituents; &c. &c.	68
(Coloured diagrams I. and II., facing p. 69.)	
Summary	75

III.—AVERAGE ANNUAL PRODUCE OVER THE LAST TWELVE YEARS; HARVESTS 1852-1863 INCLUSIVE.

	PAGE
Introductory observations (table, pp. 78-9)	76
Without manure	77
By farmyard manure	80
By mineral manure alone	81
By mineral manure and ammonia salts	83
By ammonia salts, alone, in alternation with mixed mineral manure, and in conjunction with different descriptions of mineral manure ..	85
By nitrate of soda, alone, and in conjunction with mineral manure ..	87
On plots 15a, 15b, and 19	89
Summary	90

IV.—AMOUNT OF INCREASED PRODUCE OBTAINED FOR A GIVEN AMOUNT OF AMMONIA SUPPLIED IN MANURE.

Introductory observations	92
Results according to the amount of ammonia employed, and to the available supply of mineral constituents	95
Results according to season	97
Conclusion	98

V.—CONCLUDING OBSERVATIONS, SHOWING THE PRACTICAL BEARINGS OF THE RESULTS.

Brief recapitulation, and statement of the question	98
Accordance of the results with those obtained in direct experiments on other soils	100
Accordance of the results with the common experience of practical agriculture in Great Britain	102
Actual conditions of British agriculture in regard to the import and export of mineral constituents, and to the supplies of available nitrogen; with general considerations regarding exhaustion	102

APPENDIX.

Tables I.-XXVI. inclusive, pp. ii.-xli.

REPORT

OF

EXPERIMENTS ON THE GROWTH OF WHEAT.

THE records of a field of 14 acres in which wheat has been grown without manure, and by different descriptions of manure, year after year for twenty successive seasons, without either fallow or a fallow crop, and in which the lowest produce was in the first year 15, and in the last $17\frac{1}{2}$ bushels, and the highest in the first year $24\frac{1}{2}$, and in the last $56\frac{1}{2}$ bushels, cannot fail to be of much interest at once to the practical farmer, to the economist, and to the man of science. Accounts there have been before, of the growth of wheat for many consecutive years apparently with great success, and without much evidence of exhaustion, on soils of admittedly extraordinary fertility; and the recent experience of the Rev. S. Smith, of Lois Weedon, has shown that, on his soil at least, many wheat-crops can be taken, under a system of alternate crop and fallow, without reaching, at any rate for many years, the point of deterioration. History also tells us of large tracts of land on which the wheat-crop has been cultivated year after year for many years, but which have eventually succumbed to the unnatural strain put upon them. The records to be laid before the reader in the present paper refer to conditions of growth like in some points, but essentially different in most, to those of the cases to which allusion is here made.

The experiments have been made upon what may be called fair average wheat-land. But, as the rental of similar land in the immediate locality ranges, and has ranged for many years past, only from 25s. to 30s. per acre, tithe free, and its wheat-crop under the ordinary management of the district certainly does not average more than from 25 to 27 bushels per acre once every five years, it is obvious that, in a practical point of view, it can lay no claim to extraordinary fertility, or to be ranked on a higher level than a large proportion of the soils on which wheat is grown with a moderate degree of success under a system of rotation and home manuring. Such, in an agricultural or commercial point of view, were the general characters of the land. Speaking still in agricultural language, it may be said that the soil is a somewhat heavy loam, with a subsoil

of raw yellowish red clay, but resting in its turn upon chalk, which provides good natural drainage.

The questions arise:—What are the grain-yielding capabilities of such land?—what its powers of endurance?—in what constituents, or class of constituents, does it soonest show signs of exhaustion?—and how far will the answers arrived at on these points in reference to it, accord with, or be a guide to, those which would apply to any large proportion of the arable land of Great Britain when farmed in the ordinary way, with rotation?

When this Journal first appeared, now five-and-twenty years ago, such questions as these were hardly thought of, excepting by a few philosophers and economists whose speculations were scarcely heard of, and still less heeded, by any considerable number even of the most intelligent of agriculturists. Since that period, however, matters have very much changed; and the history of the change shows it to have been due to by no means one cause alone. Almost coincidently, or at any rate following very closely upon one another's footsteps, and each reacting upon the other, the increase of population, commercial freedom and competition, a vast increase in scientific knowledge, and extensive diffusion both of it and of information of a practical kind bearing upon the farmer's art, have contributed to the wide-spread spirit of enquiry of the present day on such subjects.

But it is especially to the laborious investigations on agricultural chemistry of Boussingault, and to the generalisations of Liebig to a great extent founded upon them, nearly a quarter of a century ago, that we must attribute much of the stimulus and direction that has been given to chemical enquiries in connexion with agriculture in recent times.

As bearing upon the plan adopted in our own experiments, it may be well very briefly to recall attention here, to the state of knowledge and opinion on some important points, about the time of their commencement, and during the earlier years of their progress.

Leaving out of view the many important preliminary points established by others, which were essential as a starting-point for Boussingault's researches, it may be stated that already before 1840, that indefatigable and most careful experimenter had determined, as far as the then known analytical methods permitted, the amounts of the most important constituents of agricultural produce put upon the land in the manure, and taken off in the crops, through several courses of rotation. His more important conclusions, stated in a very few words, were—that much more carbon and nitrogen were removed in the crops than were supplied in the manure; that the best rotations were those which accumulated the most of those constituents from the atmosphere; that some plants, especially Leguminosæ, accumulated more

nitrogen from the atmosphere than others, and not only contained more in their removed produce, but by their residue left the land richer in nitrogen than it was before; and that the value of manure was to a great extent measurable by the amount of nitrogen it contained.

In Liebig's first work on 'Organic Chemistry in its applications to Agriculture and Physiology,' published in 1840, he illustrated, more pointedly than Boussingault had done, the importance of the incombustible or ash-constituents; which, to distinguish them from carbonic acid, water, and ammonia, from which the organs of plants were in great part formed, he designated as "inorganic" substances. He, at the same time, also insisted strongly upon the importance of the nitrogen, or ammonia-yielding matter, of manures.

Soon after the appearance of Liebig's work, Boussingault published, much more fully, the results of his own agricultural investigations, and the conclusions deducible from them, bringing out more prominently his views as to the importance, in a practical point of view, of the nitrogen in manures.

Liebig followed with a new edition in 1843, in which he criticised Boussingault's experiments; condemned his notion of the relative importance of the nitrogen of manures; maintained (in direct opposition to the view put forward in his former edition) that the atmosphere afforded a sufficient supply of nitrogen for cultivated as well as for uncultivated plants; argued that this supply was sufficient for the cereals as well as for the Leguminous plants; that it was not necessary to supply nitrogen to the former; and insisted very much more strongly than formerly on the relative importance of the incombustible, or, as he designated them, the "inorganic" or "mineral" constituents. He even went so far as to say:—

"Is fertility not quite independent of the ammonia conveyed to the soil? If we evaporated urine, dried and burned the solid excrements, and supplied to our land the salts of the urine, and the ashes of the solid excrements, would not the cultivated plants grown on it—the gramineæ and leguminosæ—obtain their carbon and nitrogen from the same sources whence they are obtained by the gramineæ and leguminosæ of our meadows?

"There can scarcely be a doubt with regard to these questions, when we unite the information furnished by science to that supplied by the practice of agriculture."—3rd Ed., p. 204.

Again—

"The crops on a field diminish or increase in exact proportion to the diminution or increase of the mineral substances conveyed to it in manure."—3rd Ed., p. 211.

Somewhat later, he said—

"It has been demonstrated that ammonia is a constituent part

of the atmosphere, and that as such it is directly accessible and absorbable by all plants. If, then, the other conditions necessary to the growth of the plants be satisfied—if the soil be suitable, if it contains a sufficient quantity of alkalies, phosphates, and sulphates, nothing will be wanting; the plants will derive their ammonia from the atmosphere, as they do carbonic acid. We know well that they are endowed with the faculty of assimilating these two aliments; and I really cannot see why we should search for their presence in the manures we use.”

“ The question of the necessity for ammonia in our manures resolves itself into the question of the necessity for animal manures, and upon the solution depends the entire future prospects of agriculture; for as soon as we can dispense with bulky farmyard manure, by the use of artificial preparations, the productive power of our fields is placed in our own hands.”

Our former papers published in this Journal have shown that the results of direct experiment, as well as the general experience of agriculture as practised in this country, are in the main confirmatory of the conclusions of Boussingault, and ‘condemnatory of those of Liebig, as above quoted; and the records of continued investigation given in this paper will afford further evidence in the same direction, in reference to some of the points in question.

In his more recent works, however, Baron Liebig substantially affirms much of what we have from time to time maintained in correction of his own special doctrines. One example will suffice. In his most recent work—‘The Natural Laws of Husbandry’—in the course of a good deal of illustration bearing upon the point, he says:—

“It is easy to see that the accumulation of nitrogenous food by farmyard manure in the uppermost layers of the ground, so very important for the perfect growth of cereal plants, must chiefly depend upon the successful growth of fodder plants.”

Here, then, in direct contradiction to the views embodied in the sentences above quoted from his earlier writings, Baron Liebig now maintains the importance of the growth of fallow crops as a means of providing nitrogenous manures for the growth of the cereal grains. He does so, however, not only without any acknowledgment of previous error on the point, but, as in other instances, seeks to cover his change of view by putting forth his present opinions as apparently only the necessary consequences of general or abstract principles laid down by himself, and by misrepresentation and ridicule of those whose corrections he adopts.

Prior to the appearance of Baron Liebig’s work in 1840, numerous experiments, to a great extent suggested by a study of De Saussure’s researches on vegetation, had been made, on a

small scale, at Rothamsted, on the effects of various mineral and other substances when applied as manure to a variety of agricultural plants. The most marked result observed in these early trials was the very striking increase in the rapidity of growth of certain plants when earthy phosphates decomposed by sulphuric acid were employed.

In 1843, it was decided to make experiments at once more systematic and on a larger scale, on some of the most important crops of our rotations, to determine, as far as possible, the relative or characteristic dependence of each, on the soil, the atmosphere, and manure. Boussingault's researches had been designed to ascertain what constituents were furnished, respectively by the soil, the atmosphere, and manure, to the aggregate of crops forming a rotation, rather than to each description of plant individually; and he himself says that his plan and results were silent on the latter point, though there is no doubt they did, at the same time, afford some very trustworthy indications in relation to it.

Of the new series of experiments made at Rothamsted, the first commenced was on turnips; and in accordance with the results previously obtained on a small scale, and apparently quite consistently with the views put forth by Liebig as to the relative importance of supplying the mineral constituents, the effects of the phosphatic manures were most striking, especially in the early stages of growth; though, when the experiments of the first year were concluded, it was found that certain organic manures had very materially influenced the final amount of produce.

For the experiments upon wheat, a field of 14 acres was selected, which had grown turnips, barley, peas, wheat, and oats, since the application of manure, and would, therefore, according to the ordinary rules of practice, be considered so far exhausted as to require to be re-manured before growing another crop.

It was thought that a field in such a condition was peculiarly fitted to show in which of the constituents of the crop to be grown the soil had become practically the most deficient by the removal of the five preceding crops; and that, if, on some plots of the land, in this agricultural sense exhausted, certain constituents of farmyard manure were supplied separately, on others in combination, and if, on others by their side, the crop were grown respectively without manure, and with farmyard manure itself, the comparative results obtained would far more satisfactorily indicate what constituents were the most exhausted, so far as their available supply for the crop to be grown was concerned, than any analysis of the soil could do.

This view has been fully confirmed, not only by the results obtained on the plan adopted, but by those obtained by others

who have attempted to determine on what depends the productive condition of a soil, by means of the chemical analysis of soils of different physical characters, and of known different productive qualities. The opinions of Professor Magnus, put forth some years later, in his report upon forty-two analyses of soils made under the auspices of the Landes-Oekonomie Kollegium of Prussia, to which he was then chemist, abundantly confirm the propriety of the decision at which we arrived, after a very careful consideration of the subject at the commencement of our experiments.

Our conclusion, as indicated in former papers, and frequently expressed in answer to the objections of chemical friends who had not paid special attention to the applications of chemistry to agriculture, was, that far more had yet to be done in determining the chemical and physical qualities of soils in relation to the atmosphere, and to manurial substances exposed to their action, as well as in perfecting methods of analysis, before comparative analyses could aid us much in deciding upon the relative productiveness of different soils, to say nothing of the still more difficult problem of estimating, by such means, the condition of fertility or exhaustion of one and the same soil at different times. Of late years very much has been done in these departments of investigation; still, as recent discussions abundantly show, far too little is even yet known of what a soil either is or ought to be, in a chemical point of view, to render the results of the analysis of soils directly applicable to the solution of questions such as those we had in view in our enquiry. But if our knowledge of the chemistry of soils should progress as rapidly as it has during the last twenty years, the analysis of a soil will ere long become much more significant than it is at present.

In the mean time, therefore, the synthetic rather than the analytic method was relied upon. And it was with the striking effects of the mineral manures upon the still growing turnip-crop under our view, and wishing to test more fully the recently-promulgated doctrines of Liebig, that the plan of the first of the twenty years of experiments with wheat was arranged. Under the influence of such experience, and of such theoretical considerations, "inorganic" or "mineral" manures of some kind were applied to almost every plot, and nitrogenous ones to very few. Without anticipating in these preliminary remarks the results which will be given in detail further on, it may be stated generally, that in this first season scarcely any increase whatever was obtained from the exclusive application of any of the so-called mineral manures; whilst, wherever nitrogenous manures were employed the effect was very striking.

Naturally enough much more nitrogen (as ammonia or in some

other available form) was employed in subsequent seasons; and so marked have been its effects, that the interest of the investigation may be said almost to begin and end with the consideration of the influence of that important constituent of manures on the amounts and character of the produce obtained, in immediate or succeeding crops, according to the quantity employed, to the condition of the land in regard to the supply of available mineral constituents, and to the characters of the seasons.

THE FIELD EXPERIMENTS.

The particulars of the manuring and produce of each of the experimental plots, in each of the twenty years over which the experiments have extended, are given in detail in Tables I. to XXI. inclusive, in the Appendix; and in Tables XXII. to XXVI. inclusive, also in the Appendix, are given some of the most important results in a more collective form. Those voluminous records, as above classified, show, respectively, the effects of one manure compared with another in each season separately, and the great difference of effect of the same manure in one season compared with another, and its increasing or diminishing effect when used year after year on the same plot.

It will be obvious, however, on a very little reflection, that the question of the relative condition of exhaustion of the different plots cannot be satisfactorily considered by reference to the amounts of crop alone. To deal adequately with this part of the subject, the consideration of the chemical composition, as well as the amount, of the produce is obviously essential. Accordingly, the proportions of dry substance, and of mineral matter, in both the corn and the straw, of each plot, in each of the twenty years, have been estimated. The proportion, and amount per acre, of the nitrogen, and the composition of the ash, in both corn and straw, have in many selected cases been determined. The percentage of nitrogen in the soil of some of the plots, at different stages of the progress of the experiments, has also been estimated. The mere tabular record of these results of analysis would occupy nearly as much space as those relating to the experiments in the field; whilst the discussion of them, in their manifold and important bearings, would supply matter more than sufficient for a single paper. It is proposed, therefore, on the present occasion, to leave out of view the analytical results altogether, and to confine attention, almost exclusively, to the more salient points of interest brought out by the results of the field experiments alone, leaving the detailed treatment of the question of exhaustion to a future opportunity.

The question of the climatic characters of the different seasons, and of the connexion between these and the amount and character of the produce yielded, would also require, for its due illustration

and elucidation, the discussion of such a vast amount of meteorological record, and is, moreover, one of such intricacy, that it would be impossible to treat it at all satisfactorily within the limits that might otherwise have been devoted to so interesting and important a branch of the subject in the present paper. The consideration of the influence of season will, therefore, on the present occasion, be limited to pointing out, as matters of fact, the most prominent characteristics of the respective seasons, and the very great difference in the amounts and in the characters of the produce obtained under otherwise comparable conditions of growth, but in different seasons.

Incidentally, however, the results brought out under this head will enable us to form some judgment as to whether the earlier or the later seasons of the experiments were, upon the whole, the less or the more favourable; and, therefore, whether an increased or diminished result from the use of the same manure through successive years, is to be attributed mainly to the cumulative or the defective character of the manure itself, or, in any material degree, to a progressive or retrogressive character of the seasons.

General Description of the Manures employed.

Having regard to the constituents of the ash of wheat-grain, and of wheat-straw, it was sought to supply potass, soda, lime, magnesia, phosphoric acid, sulphuric acid, chlorine, and silica, respectively, in the most available and convenient forms. Omitting from the enumeration the amounts of mineral constituents provided in farmyard manure, cut wheat-straw, rape-cake, &c., or in the ashes of farmyard manure or wheat-straw, the more direct supply of the above-mentioned substances was as under:—

Potass—As pearl-ash, sulphate of potass, or silicate of potass.

Soda—As soda-ash, or sulphate of soda.

Lime—As sulphate, phosphate, and superphosphate.

Magnesia—As magnesian lime-stone, or sulphate of magnesia.

Phosphoric Acid—As bone-ash; generally acted upon by sulphuric acid in quantity sufficient to convert a considerable portion of the insoluble earthy phosphate of lime into sulphate and soluble superphosphate of lime.

Sulphuric Acid—As sulphate of potass, soda, or magnesia, in the phosphatic mixture last mentioned, &c.

Chlorine—As hydrochloric acid (with bone-ash), or as chloride of sodium (common salt), &c.

Silica—As artificial silicate of potass; formed by fusing together equal parts of sand and pearl-ash.

In accordance with the nomenclature employed by Liebig, and generally adopted by writers on agricultural chemistry, all the above are, for convenience, distinguished as "inorganic" or "mineral" manures. Professor Hofmann* has, however, recently suggested the term *cinereal* (from *cineres*, ashes) to designate those constituents which are found in the ashes of plants. Although, undoubtedly, far more appropriate than the terms "inorganic" or "mineral," the attempt to substitute it now would be fraught with more inconvenience and confusion than advantage. Liebig himself, has, indeed, of late, sought to repudiate the use of the term *mineral* in the restricted sense in which he had habitually used it in agricultural discussions. He has even attempted, by means of direct misquotation, to fix the origination of the distinction upon ourselves.†

Other constituents have been supplied as under:—

Nitrogen—As sulphate, muriate, or carbonate of ammonia, or nitrate of soda, of commerce; in farmyard manure, and in nitrogenous organic matter, such as rape-cake, &c.

Non-nitrogenous organic matter, yielding by decomposition carbonic acid, and other products—In rape-cake, rice, tapioca, and also in straw and in farmyard manure.

The artificial manure or mixture for each plot, was generally ground up with a sufficient amount of clay-ashes to make it up to such a fixed measure per acre as would facilitate its equal distribution over the land. In the earlier years the mixtures so prepared were sown broadcast by the drill; but they have for some time past, with proper precautions, been distributed by hand, as it was found that in that way the application of an exact amount of manure to a limited area of land could be best accomplished. Now, however, a drill has been constructed expressly for the purpose of the application of the experimental manures.

The field of 14 acres was at first divided into plots of which most consisted of two lands (each about 12 feet 5 inches wide) running the whole length of the field, and comprising together nearly two-thirds of an acre. After the second season, however, the double-land plots were each divided into two; though, in most cases, the two were similarly manured, thus providing duplicate experiments with the same manure.

* 'Reports of the Juries' of the International Exhibition of 1862; footnote, pp. 159, 160. Professor Hofmann has also, in his capacity of International Reporter, passed a judgment on the controversy between Baron Liebig and ourselves; fortunately, however, Baron Liebig's own works, and our own papers in this Journal, and elsewhere, remain in enduring protest against his misstatement of the issues, and his caricature of our own opinions.

† For further evidence on this point, see footnote at pp. 506-8, Vol. xxiv. of the 'Journal of the Royal Agricultural Society of England,' also pp. 447, 448, and context, Vol. xvi.

In the earlier years of the experiments the manures were each season allotted with a view to the settlement of certain individual points; such, for instance, as the effect of individual mineral manures, the necessity or otherwise of providing carbonaceous organic matter, and the effect, on the one hand of a deficient or partial, or on the other, of a full or excessive, manuring in one season on the crop of the immediately succeeding season. The allotment was always made with more or less of special reference to the previous manuring and produce of the respective plots; but, unfortunately, not with that full appreciation of the desirableness of maintaining exactly and easily comparable relations between one plot and another for a long series of consecutive seasons, which, in this hitherto untrodden path of inquiry, could only be attained by a careful study of the results from time to time obtained.

The manures applied on one and the same plot were, indeed, much more uniform from year to year after the first three, or even in many cases after the first two years of the experiments. There were, however, still some variations in the description, and more in the amount employed on the same plot, even up to the eighth year inclusive; though, during the last four of these, there were comparatively few the effect of which would be to interfere materially with the comparative character of the results obtained in subsequent seasons.

In the ninth year it was definitively arranged to supply, throughout the field, the same manure year after year, on the same plot, for many successive seasons, so as to trace more clearly the point at which one or another constituent became exhausted, or in excess, in relation to others, or to the requirements for the production of a maximum crop.

It is obvious, therefore, that when comparing the results obtained on one plot with those of another in the ninth and eleven succeeding seasons, the previous history of each plot must be taken into consideration. Numerous illustrations will, indeed, be given of the effects of the unexhausted residue of nitrogenous and mineral manures applied in preceding seasons, on the amounts of produce obtained in succeeding ones; not only, however, with a view to the more correct interpretation of the results obtained in the later years of these experiments, but also on account of the great practical importance of the question. But it will be when we come, on a future occasion, to discuss the deficiency or excess of certain constituents by the aid of analysis, that we shall enter more fully into the chemical statistics of each individual plot than is necessary, or even desirable, in presenting the outline of the results in their more practical bearings which it is proposed to give in the present paper.

THE FIELD RESULTS.

In former numbers of this Journal (vol. viii. part 1; vol. xii., part 1; and vol. xvi., part 2), the most important of the results obtained in the earlier years have been discussed; and to those papers, and to the detailed records given in the Appendix Tables at the conclusion of this paper, the reader is referred for any more than the very brief notice of the experiments of the first eight years which can now be given.

On the present occasion the results of the whole 20 years will be treated of under the following separate heads:—

First.—*Amount and character of the produce obtained under the different conditions of manuring, in each of the 20 years; with brief reference to the characters of each season.*

Second.—*Effects of the unexhausted residus from previous manuring (both nitrogenous and mineral) upon succeeding crops.*

Third.—*Average annual result over the last 12 years, by each description of manure applied year after year on the same plot.*

Fourth.—*Amount of ammonia in manure required to yield one bushel increase of grain (with its proportion of straw), according to the quantity applied per acre, to the available supply of mineral constituents within the soil, and to the season.*

Fifth.—*Concluding observations; showing the practical bearings of the results.*

I.—AMOUNT AND CHARACTER OF THE PRODUCE OBTAINED IN DIFFERENT SEASONS.*

First Season, 1843-4.

The winter of 1843-4 was unusually mild until the end of January. February and March were cold, wet, and stormy. April and May were unusually dry, with some warm weather, but a good deal of cold easterly wind. June was variable as to temperature, with scarcely any rain throughout the greater part of it, but a good deal towards the end of the month. July was wet, but with more than the average temperature, especially during the last week. August was almost throughout colder than usual, and excepting towards the end, windy and wet. In September a moderate amount of rain fell, but the weather was, upon the whole, warm and favourable. The dew-point and the degree of humidity of the air were, in June below, and in July about the average; in August the dew-point was low, but with the prevailing low temperature the degree of humidity was high; and in September both dew-point and degree of humidity were above the average.

* The observations on the characters of the seasons are founded partly on Mr. Glaisher's Quarterly Reports, and partly on other records, and they, as well as those relating to the wheat-crops of the country, may be taken as applicable, so far as such brief and general statements can be, to a considerable portion of the Midland, Eastern, and South-eastern districts of England.

With these characters of season, which proved extremely adverse to grass and spring-sown crops, the wheat-crop was reported to be generally well got in, and to be one of the largest in bulk and yield for many years past.

The amount and character of the produce obtained in the experimental field is sufficiently indicated by the following summary of the results yielded on some of the most important plots:—

TABLE I.—SUMMARY of the Results of the FIRST SEASON, 1843-4.

MANURES. (Quantities per Acre.)	PRODUCE PER ACRE, &c.			
	Dressed Corn.		Total Corn.	Straw and Chaff.
	Quantity.	Weight per Bushel.		
	Bush. Pks.	lbs.	lbs.	lbs.
Unmanured (Plot 3)	15 0	58·5	923	1120
14 tons Farmyard Manure (Plot 2)	20 1½	59·3	1276	1476
Ashes of 14 tons Farmyard Manure (Plot 4) ..	14 2½	58·0	888	1104
Mixed Mineral Manure alone; mean of 9 plots (5, 6, 7, 8, 10, 12, 13, 14, and 15)	15 2½	61·0	1009	1155
Mixed Mineral Manure, and 65 lbs. Sulphate of Ammonia; mean of 3 plots (9, 16, and 17) ..	19 1½	62·3	1275	1423
Mixed Mineral Manure, and 80 lbs. Sulphate of Ammonia (Plot 19)	24 1½	61·8	1580	1772

It will be observed that notwithstanding the very favourable report of the year's crop, the produce in these experiments was, without manure only 15 bushels, and with farmyard manure scarcely 20½ bushels of dressed corn, with proportionally small amounts of straw. These low results afford satisfactory evidence that the land was in a condition of practical or agricultural exhaustion; and hence, that it was well fitted for the purpose of experiments the object of which was to show in what constituent, or class of constituents, the soil had become, by the previous course of cropping, the most deficient, so far as the requirements of the wheat-crop were concerned.

It is specially worthy of remark, too, that on land in this condition, the ashes, or mineral constituents, of farmyard dung, gave no increase whatever, and artificial mineral manures did so to the amount of less than a bushel of dressed corn, and only 35 lbs. of straw. On the other hand, mineral manure and only 65 lbs. of sulphate of ammonia per acre, gave nearly as much produce as the farmyard manure; whilst one experiment, in which 80 lbs. of sulphate of ammonia were employed with mixed mineral manure, gave the highest produce obtained in that year, and nearly 4 bushels of corn, and 300 lbs. of straw, more than was yielded by the farmyard manure.

The obvious conclusion was, that, by the ordinary course of cropping to which the land had been subject, the soil had become deficient in available nitrogen relatively to the available supply of mineral constituents required by the wheat-plant.

Second Season, 1844-5.

November, 1844, was comparatively warm, with a good deal of rain. December was unusually severe throughout. January (1845) was very wet and mild. February and the greater part of March were extremely cold, the thermometer on several occasions showing lower temperatures than had been observed for many years, and at intervals a good deal of snow fell. April was cold, but, upon the whole, dry; and May was cold, wet, and unseasonable. In June not much rain fell, and the weather was pretty warm throughout; but July and August were generally both cold and wet. September, too, was cold throughout, with an excess of rain during the latter half of the month. In June, the dew-point was considerably above, in July about, and in August and September somewhat below the average; but, in each of these months, the degree of humidity of the air was notably above the average.

The wheat-crop of 1845 was generally deficient in bulk, yield, and quality. It was in this season that the potato disease first appeared to any extent.

The following is a summary of the results obtained in the experimental field:—

TABLE II.—SUMMARY of the Results of the SECOND SEASON, 1844-5.

MANURES. (Quantities per Acre.)	PRODUCE PER ACRE, &c.			
	Dressed Corn.		Total Corn.	Straw and Chaff.
	Quantity.	Weight per Bushel.		
Unmanured (Plot 3)	Bush. Pks.	lbs.	lbs.	lbs.
14 tons Farmyard Manure (Plot 2)	23 0½	56·5	1441	2712
2 cwts. Carbonate of Ammonia (top-dressed in solution), Plot 5	32 0	56·8	1967	3915
26 3¼	26 3¼	57·3	1732	3599
3 cwts. Ammonia-salts (equal parts Sulphate and Muriate); mean of 2 plots (9 and 10) ..	32 2½	57·3	2056	4162
2 cwts. Ammonia-salts (equal parts Sulphate and Muriate) and Superphosphate of Lime (plot 18)	33 0½	56·5	2048	3819
2 cwts. Sulphate of Ammonia, 5 cwts. Rape-cake, and Mineral Manure; mean of 3 experiments (plots 1, 11, and 12)	28 2½	55·3	1804	3979

Owing to the very unfavourable winter of 1844-5, severe frost

alternating with a great deal of rain, it was impossible to prepare the land and sow the manures and seed in the experimental field until March, 1845; and, as the above statement shows, the period from seed-time to harvest was, with the exception of June, almost uniformly cold, wet, and unseasonable. Further, as already referred to, mineral manures were applied on very few, and ammonia-salts, or rape-cake, on most of the plots.

As above stated, the wheat-crop of the country was reported to be generally deficient in quantity as well as quality; but in the experimental field, although the quality, as indicated by the weight per bushel, and the proportion of corn to straw, was low, the bulk and weight of total produce were above the average of the 20 years under comparable conditions of manuring. Indeed, both without manure, and with farmyard manure, the produce of corn was about $1\frac{1}{2}$ time, and that of straw about $2\frac{1}{2}$ times as much as in the reputedly very much more favourable season of 1844.

The produce without manure being $23\frac{1}{2}$ bushels, and that by farmyard manure 32 bushels, 3 cwts. of ammonia-salts per acre (succeeding a mineral manure in the previous season) gave $32\frac{1}{2}$ bushels of corn and 4162 lbs. of straw, or more both of corn and straw than the 14 tons of farmyard manure; whilst only 2 cwts. of ammonia-salts per acre, but used in conjunction with mineral manure (plot 18), gave even rather more corn, and not much less straw.

It is unfortunate that mineral manure was in no case used alone in this season. But the effects of ammonia-salts, as in the preceding season, are very striking. It is also seen, by a comparison of the result of 2 cwts. of ammonia-salts with mineral manure, with that of 3 cwts. without it (though succeeding mineral manure in the previous season), that the mineral constituents supplied, though so inactive when used alone in the preceding year, had a very marked effect when a sufficient amount of ammonia was at the same time provided within the soil. The influence of the mineral manure was, moreover, very much to increase the tendency to the production of corn rather than of straw.

Third Season, 1845-6.

Throughout the winter of 1845-6 the temperature was generally above, and sometimes considerably above, the average. In December and January there was a great deal of rain, but in November and February less than the average. The first part of March, too, was considerably warmer than usual, with little rain. It then became colder, and towards the end of the month there was frost and snow. The beginning and end of April were

rather cold, but otherwise the month was mild, with a good deal of rain. May was very fine, the temperature being much above, and the rain-fall much under the average. June was very unusually hot and dry until towards the end of the month, when the weather broke up with a thunder-storm. July was variable, but, upon the whole, seasonable, with a good deal of very hot weather, and but little rain. In the beginning of August there was great heat with heavy thunder-storms, and excessive amount of rain, the rest of the month being favourable. September was also generally warm and favourable, but with a fair amount of rain towards the end of the month. The dew-point generally ranged high throughout June, July, August, and September; but, with the prevailing high temperatures, the degree of humidity of the air was, in June and July somewhat below, and in August and September not much above the average.

Upon the whole, the winter, spring, and summer of 1845-6 were unusually warm, the summer dry, and the harvest-time generally favourable.

With these qualities of season, the wheat-crop of the country was estimated to be below the average in amount, but to be of very good quality.

In the experimental field mineral manures were employed more generally, in greater variety, and in greater abundance, than in the preceding season. Ammonia-salts, or rape-cake, or both, were also used on many of the plots. Among the mineral manures, the ashes of wheat-straw, and Liebig's wheat-manure, were respectively employed alone, with ammonia-salts, with rape-cake, and with both ammonia-salts and rape-cake. Upon the whole, there was more of uniform plan in the selection and arrangement of the manures in this season than formerly; and, as already referred to, the double-land plots were now, and henceforth, subdivided; though, especially in the later years of the experiments, the two lands designated *a* and *b* respectively, generally served as duplicates with the same manure. Passing over all details, Table III. (p. 20) is a summary of the results obtained in this season.

The experimental wheat-crop of 1846 was by no means so bulky as that of 1845; but (as also over a large area of the country) the quality was very much above the average, both the proportion of corn to straw, and the weight per bushel of dressed corn, being very high.

Taking the unmanured produce of dressed corn as the standard for comparison, the farmyard manure gave an increase of $9\frac{1}{2}$ bushels; mineral manure alone (though succeeding ammonia-salts or rape-cake, or both, in the preceding season), of under 3 bushels; 2 cwts. of sulphate of ammonia alone (after ammonia-salts in the preceding year, and mineral manure

TABLE III.—SUMMARY of the Results of the THIRD SEASON, 1845-6.

MANURES, (Quantities per Acre.)	PRODUCE PER ACRE, &c.				
	Dressed Corn.		Total Corn.	Straw and Chaff.	
	Quantity.	Weight per Bushel.			
Unmanured (Plot 3)	Bush. Pks.	lbs.	lbs.	lbs.	
14 tons Farmyard Manure (Plot 2)	17 3½	63·8	1207	1513	
Mixed Mineral Manures; mean of 4 experi- ments (Plots 1, 5a ¹ , 6a, and 18b)	27 0½	63·0	1826	2454	
2 cwt. Sulphate of Ammonia alone (Plot 10a)	20 3	63·0	1422	1766	
2 cwt. Ammonia-salts (equal parts Sulphate and Muriate), and Mixed Mineral Manure; mean of 9 experiments (Plots 5a ² , 6b, 8b, 11b, 12b, 13b, 14b, 17b, and 18a)	27 1½	63·6	1850	2244	
4 cwt. Rape-cake, and Mixed Mineral Manure; mean of 8 experiments (Plots 5b ¹ , 7a, 8a, 11a, 12a, 13a, 14a, and 16a)	29 0½	63·2	1965	2626	
2 cwt. Ammonia-salts (equal parts Sulphate and Muriate), 4 cwt. Rape-cake, and Mixed Mineral Manure; mean of 4 experiments (Plots 5b ² , 7b, 16b, and 17a)	23 2½	63·2	1603	2047	
	31 2	63·1	2125	3006	

in the year before that), 9½ bushels; 2 cwt. of ammonia-salts and mineral manure, rather over 11 bushels; 4 cwt. rape-cake and mixed mineral manure, 5½ bushels; and 2 cwt. ammonia-salts, 4 cwt. rape-cake, and mixed mineral manure, 13½ bushels.

Thus, under the influence of this hot and dry summer, the ammonia-salts alone gave rather more corn, and not much less straw, and the ammonia-salts and mineral manure together more of both corn and straw, than the farmyard manure; whilst mineral manures alone gave very much less produce than ammonia-salts alone. Here again, then, in a very different season, and in the third of the growth of wheat on the same land, the inefficiency of mineral manures alone, and the marked effect of nitrogenous manures, are very striking.

Fourth Season, 1846-7.

Until the end of November, 1846, the season was mild and favourable. December, January, February, and considerable part of March, were extremely cold, with intense frosts, and much fog, and, towards the end of February, deep snow; January was, however, less rigorous than the other months. The remainder of March, the whole of April, and the early part of May were still unusually cold, with but little rain until towards the end of April, after which there was a good deal. The latter part of May and the beginning of June were fine, with a good deal of high temperature; but during the latter part of June more than the usual amount of rain fell, and the temperature was also below the

average. July was, upon the whole, fine, sometimes excessively hot, with little distributed rain, but a good deal in a heavy thunderstorm towards the end of the month. In August, again, not much rain fell, but it was distributed over the whole month. September was showery, windy, and generally of rather low temperature, but still, upon the whole, favourable. In June, both dew-point and degree of humidity of the air were rather below the average; in July the dew-point was above, but the degree of humidity below the average; in August, both dew-point and degree of humidity were considerably above the average; and in September the dew-point was low, but with the prevailing low temperatures the degree of humidity was rather high.

Both the yield per acre, and the quality of the grain, of the harvest of 1847, were reported to be generally above the average.

In the experimental field mineral manures were in no case employed alone in this season; neither potass, soda, nor magnesia was used. Superphosphate of lime was applied in smaller quantity than in the preceding year, but on nearly the same plots; ammonia-salts in rather larger quantity; and rape-cake not at all; but rice, as a means of supplying decomposing organic matter containing much less nitrogen than rape-cake, was applied in a few instances in large quantity per acre. The following is a summary of the most characteristic results:—

TABLE IV.—SUMMARY of the Results of the FOURTH SEASON, 1846-7.

MANURES (Quantities per Acre.)	PRODUCE PER ACRE, &c.			
	Dressed Corn.		Total Corn.	Straw and Chaff.
	Quantity.	Weight per Bushel.		
Unmanured (Plot 3)	Bush. Pks.	lbs.	lbs.	lbs.
14 tons Farmyard Manure (Plot 2)	16 3 $\frac{1}{4}$	61·0	1123	1902
300 lbs. Ammonia-salts (equal parts Sulphate and Muriate); mean of 8 experiments (Plots 6a, 6b, 7a, 7b, 9a, 9b, 10a, and 10b)	29 3 $\frac{1}{4}$	62·3	1981	3628
300 lbs. Ammonia-salts (equal parts Sulphate and Muriate), and Superphosphate of Lime; mean of 14 experiments (Plots 5a, 11a, 11b, 12a, 12b, 13a, 13b, 14a, 14b, 16a, 16b, 17a, 18a, and 18b)	25 3 $\frac{1}{4}$	61·6	1711	2921
400 lbs. Ammonia-salts (equal parts Sulphate and Muriate), and Superphosphate of Lime; mean of 2 experiments (Plots 8b and 17b)	29 3 $\frac{1}{4}$	62·3	1991	3502
300 lbs. Ammonia-salts (equal parts Sulphate and Muriate), Superphosphate of Lime, and 500 lbs. Rice; mean of 2 experiments (Plots 5b and 8a)	33 0 $\frac{1}{2}$	61·9	2167	3991
20 cwt. of Rice alone (Plot 9a ¹)	32 2	61·7	2124	3702
	22 3	..	1351	2506

Although the wheat-crop of 1847 was reported to be generally above the average, both as to yield per acre and quality, there was here, except in the case of the farmyard manure, not quite so much corn for a given amount of manure applied, nor was the weight per bushel so high, as in the preceding year. The amount of straw was, on the other hand, much greater; though, neither was it, nor that of the corn, equal to the average of the years of experiment. The quality of the grain, as indicated by the weight per bushel, was, however, considerably above the average.

By farmyard manure there was an increase over the unmanured produce of 13 bushels of corn, and 1726 lbs. of straw; and there was very nearly the same amount by 300 lbs. of ammonia-salts together with superphosphate of lime. Without the superphosphate of lime the ammonia-salts show a deficiency of nearly 4 bushels of dressed corn, and of 581 lbs. of straw. 400 lbs. of ammonia-salts with superphosphate of lime gave 33 bushels of dressed corn per acre, or an increase over the unmanured produce of about 16 bushels, and over that by farmyard manure of rather over 3 bushels of corn and of 363 lbs. of straw. By the substitution of 100 lbs. of ammonia-salts by 500 lbs. of rice, the quantity of both corn and straw was somewhat reduced; and by the use of 1 ton of rice alone, the total increase obtained was little more than one-third the weight of the manure employed.

Here again, then, in the fourth season, ammonia-salts alone gave a very considerable amount of increase, and when used in conjunction with superphosphate of lime the largest produce of the season was obtained.

Fifth Season, 1847-8.

November, December, January, and February of the winter of 1847-8 were, upon the whole, fine and mild, though there was some excessively cold weather, with dry piercing winds, sharp frosts, and snow towards the end of January and beginning of February, and during the remainder of the latter month a great deal of rain, but with comparatively high temperature. March and April were very wet and cold, excepting at the end of the former and the beginning of the latter month, when the weather was finer and warmer. May was genial, with little rain. June and July were unseasonably wet, variable as to temperature, with a good deal of cool, and but little hot weather. August also was unsettled, generally cold, and extremely wet. September was variable with some fine and hot days, but a good deal of wind and low temperature, and towards the end a good deal of rain. In June, July, August, and September, the dew-point ranged rather below the average, more particularly in August;

and the degree of humidity of the air was, in June and August slightly above, and in July and September slightly below the average.

With such prevalence of cold and wet weather during the growing and ripening period, the wheat-crop of 1848 was reported to be very deficient both in quantity and quality.

The manuring in the experimental field was generally heavier than in the preceding year. Salts of potass, soda, and magnesia, were again employed on many plots; the amounts of superphosphate of lime, and also of ammonia-salts, were generally larger; and the more highly nitrogenised rape-cake was employed instead of rice. The following is a summary of the results obtained under the above conditions of season and manuring:—

TABLE V.—SUMMARY of the Results of the FIFTH SEASON, 1847-8.

MANURES. (Quantities per Acre.)	PRODUCE PER ACRE, &c.			
	Dressed Corn.		Total Corn.	Straw and Chaff.
	Quantity.	Weight per Bushel.		
Unmanured (Plot 3)	Bush. Pks.	lbs.	lbs.	lbs.
14 tons Farmyard Manure (Plot 2)	14 3	57·3	952	1712
Mineral Manure alone; mean of 4 experiments (Plots 0, 8a, 8b, and 9a)	25 2½	58·2	1705	3041
300 lbs. Ammonia-salts (equal parts Sulphate and Muriate), Plot 10a	19 0½	57·7	1243	2121
300 lbs. Ammonia-salts (equal parts Sulphate and Muriate), Plot 10a	19 1	58·1	1334	2367
300 lbs. Ammonia-salts (equal parts Sulphate and Muriate), and Mineral Manure; mean of 4 experiments (Plots 9b, 13b, 18a, and 18b) ..	25 3½	58·7	1703	2959
400 lbs. Ammonia-salts (equal parts Sulphate and Muriate), and Mineral Manure; mean of 8 experiments (Plots 6a, 6b, 11b, 12b, 13b, 14b, 17a, and 17b)	26 1½	58·6	1763	3027
500 lbs. Ammonia-salts (equal parts Sulphate and Muriate), and Mineral Manure (Plot 5a) ..	29 3½	59·2	1991	3266
300 lbs. Ammonia-salts (equal parts Sulphate and Muriate), Mineral Manure, and 500 lbs. Rape-cake; mean of 8 experiments (Plots 7a, 7b, 11a, 12a, 13a, 14a, 16a, and 16b)	29 2½	59·1	1941	3276
400 lbs. Ammonia-salts (equal parts Sulphate and Muriate), Mineral Manure, and 500 lbs. Rape-cake (Plot 5b)	30 3½	59·1	1932	3533

With such unfavourable characters of season, the produce in the experimental field agreed with that of the wheat-crop of the country generally in being inferior both in quantity and quality. Although the manuring, both mineral and nitrogenous, was generally heavier than in 1847, or, indeed, than in any preceding season, the amount of produce was considerably less than in either 1847 or 1846, and the weight per bushel of

the grain was also considerably lower. The deficiency was not only in amount and quality of grain, but, compared with 1847, in quantity of straw also. The defective action of ammonia-salts when used without mineral manure was already observable in the results of 1847, and it is still more marked in those of 1848. Finally, 500 lbs. of ammonia-salts, in combination with mineral manure containing not only superphosphate of lime, but also potass, soda, and magnesia, gave only about the same amount of grain in the inferior season of 1848, as 300 lbs. with superphosphate of lime in 1847, or even 2 cwt. with mixed mineral manure in 1846.

Sixth Season, 1848-9.

The early part of October was fine and mild, but the latter part cold, with much heavy rain and wind; the beginning of November was very dry and cold, but the remainder of the month, and most of December, were mild, with a good deal of rain; then frost set in, which lasted, with snow and rain, till nearly the middle of January, the remainder of which month was variable as to temperature, but generally very wet. February was, for the most part, fine and mild, until nearly the end of the month, when it was much colder, very wet, and very windy. March and April were cold, and a great deal of rain fell in the latter month. May was also very wet, but fine and warm at the close. June was fine and dry, but rather cold. July dry and hot until towards the end, when there were several heavy thunder-storms. August also was fine, with the exception of some thunder-storms. September variable, with a good deal of rain in the early part. In June, July, August, and September, the dew-point was below the average; and the degree of humidity of the air was, in June slightly, but in July, August, and September, considerably below the average.

Upon the whole, then, the winter and spring of 1848-9 were mild, with a good deal of rain, and the summer and autumn, with some exceptions, seasonable and warm. The wheat-crop of the season was reported to be very abundant.

The manuring for the sixth season was much the same as for the fifth; the chief alteration being the substitution of 400 lbs. of ammonia-salts in most cases where 300 lbs. of ammonia-salts and 500 lbs. of rape-cake had been used in the preceding year.

With generally favourable weather throughout, and dry and warm weather before and about the time of harvest, the result in the experimental field, as in the country generally, was a wheat-crop above the average, both as to quantity and quality. The amount of produce for a given amount of manure was more than in 1848, 1847, or even 1846. The weight per bushel of dressed

corn was rather higher than in any other year of the experiments ; and the proportion of corn to straw was much above the average, being about the same as in 1846 and 1857, the years of highest yield of corn in proportion to straw throughout the 20 years, 1844 excepted, when it was unusually high, but when, in these experiments, the total amount of produce was very small.

TABLE VI.—SUMMARY of the Results of the SIXTH SEASON, 1848-9.

MANURES. (Quantities per Acre.)	PRODUCE PER ACRE, &c.			
	Dressed Corn.		Total Corn.	Straw and Chaff.
	Quantity.	Weight per Bushel.		
Unmanured (Plot 3)	Bush. Pks.	lbs.	lbs.	lbs.
14 tons Farmyard Manure (Plot 2)	19 1	61·4	1229	1614
400 lbs. Ammonia-salts (equal parts Sulphate and Muriate), Plot 10a	31 0	63·8	2068	3029
400 lbs. Ammonia-salts (equal parts Sulphate and Muriate), Plot 10a	32 2½	62·3	2141	2851
400 lbs. Ammonia-salts (equal parts Sulphate and Muriate), and Mineral Manure; mean of 18 experiments (Plots 6a, 6b, 7a, 7b, 11a, 11b, 12a, 12b, 13a, 13b, 14a, 14b, 16a, 16b, 17a, 17b, 18a, and 18b)	34 3	63·8	2318	3393
500 lbs. Ammonia-salts (equal parts Sulphate and Muriate), and Mineral Manure (Plot 5a)	37 1½	63·1	2446	3589
400 lbs. Ammonia-salts (equal parts Sulphate and Muriate), Mineral Manure, and 500 lbs. Rape-cake (Plot 5b)	39 3½	63·4	2651	3824

The season of 1849 seems to have been particularly favourable for the action of nitrogenous manures ; there being comparatively little deficiency where the ammonia-salts were used alone, as compared with the result with the same amount in conjunction with mineral manure ; and the excessive amounts of ammonia gave proportionally larger amounts of increase than in most of the other seasons.

Seventh Season, 1849-50.

The autumn of 1849 was generally favourable for getting in the seed. In the early part of December, and the latter part of January (1850) there was a good deal of rain, and, intermediately, pretty continued frost. February was fine and mild ; March fine, but very cold ; April very fine and seasonable until the last week, when it was much colder ; and May cold and wet in the early part, but seasonable afterwards. June, July, August, and September, were almost throughout unseasonably cold ; and there were occasional heavy rains in June and July, but during August, and the greater part of September, but little rain fell.

In June, August, and September, the dew-point was rather below, but in July rather above the average; and the degree of humidity of the air was in June considerably below, in July and August somewhat above, and in September somewhat below the average.

The harvest was late, the wheat-crops much laid, and the yield per acre was estimated to be below the average.

With few exceptions, which it is not necessary to notice here, the manures applied in the experimental field were much the same as in the two preceding seasons. The following is a summary of the results:—

TABLE VII.—SUMMARY of the Results of the SEVENTH SEASON, 1849-50.

MANURES. (Quantities per Acre.)	PRODUCE PER ACRE, &c.			
	Dressed Corn.		Total Cornage	Straw and Chaff.
	Quantity.	Weight per Bushel.		
Unmanured (Plot 3)	Bush. Pks.	lbs.	lbs.	lbs.
14 tons Farmyard Manure (Plot 2)	15 3½	60·6	1002	1719
Mineral Manure alone (Plot 0)	28 2	61·9	1861	3245
400 lbs. Ammonia-salts alone (equal parts Sulphate and Muriate) Plot 10a	19 1½	60·8	1220	2037
490 lbs. Ammonia-salts (equal parts Sulphate and Muriate), and Mineral Manure; mean of 16 experiments (Plots 6a, 6b, 11a, 11b, 12a, 12b, 13a, 13b, 14a, 14b, 16a, 16b, 17a, 17b, 18a, and 18b)	26 3½	60·2	1721	3089
500 lbs. Ammonia-salts (equal parts Sulphate and Muriate), and Mineral Manure; mean of 2 experiments (Plots 5a and 5b)	30 3½	61·0	1991	4063
400 lbs. Ammonia-salts (equal parts Sulphate and Muriate), Mineral Manure, and 500 lbs. Rape-cake; mean of 2 experiments (Plots 7a and 7b)	30 1½	60·4	1996	4442
	32 0½	61·1	2123	4383

Under the influence of the cold and unsettled summer of 1850, the produce of corn in the experimental field was several bushels less than under parallel conditions of manuring in 1849, but that of straw was considerably more; and the weight per bushel of dressed corn, though much lower than in 1849 and several other years, was above the average of the 20 years.

The proportion of increase when ammonia-salts were used alone was even greater than in some of the earlier years; in fact, only 2 bushels per acre less than where the same amount of ammonia-salts was used in conjunction with mineral manure; the quantity of straw was, however, proportionally much greater where the mineral manure was also employed. Again, unlike

the result of 1849, 500 lbs. of ammonia-salts (with mineral manure) gave scarcely as much grain as 400 lbs., but considerably more straw than the latter.

Upon the whole, the experimental crop was probably not so far inferior to the average as the wheat-crop of the country was generally estimated to be; but under the influence of the cold and unsettled summer the tendency of high manuring was to give a deficient amount of grain, and an excessive proportion of straw.

Eighth Season, 1850-1.

October (1850) was very fine, but very cold; November, December, and January (1851) were, upon the whole, fine and mild. February was generally fine, but cold. March was, for the most part, wet, cold, and windy. In April there was a good deal of rain, and the temperatures were low during the first half of the month. May and the greater part of June were dry, but unseasonably cold; July was also colder than usual, and during the month a good deal of rain fell heavily at intervals. August was very fine until nearly the end of the month, when heavy rain fell. September was fine throughout, but with rather low temperatures. In June, July, August, and September, the dew-point ranged low, but in August less, and in September more so, than in the other months; the degree of humidity of the air also was, in each of these months, below the average—less so in June and July than in August, and considerably less in August than in September.

Upon the whole, therefore, the winter was mild, the spring and a great part of the summer were cold and unsettled, but the ripening and harvest periods, though cold, were, upon the whole, fine and dry. The wheat-crop of the country was considered to be decidedly above that of 1850, both in quantity and quality, but inferior to that of 1849, especially in quantity.

In the experimental field the allotment of manures was much the same as in several preceding seasons; the chief alteration being that in a few cases the amounts of ammonia-salts and of rape-cake were increased. In one instance in this season (Plot 16a), as also in the two succeeding seasons, common salt was employed, for the results of which the reader is referred to the Appendix Tables VIII., IX., X., and XI., pp. xvi-xxi.

Under the influence of the prevailing cold and ungenial growing period of 1851, the amounts of gross produce, corn and straw together, were, under like conditions of manuring, not very different from those of 1850 and 1849; but the proportion of corn to straw was somewhat higher than in 1850, though in a greater degree lower than in 1849. Indeed, the results in the experi-

TABLE VIII.—SUMMARY of the Results of the EIGHTH SEASON, 1850-51.

MANURES. (Quantities per Acre.)	PRODUCE PER ACRE, &c.			
	Dressed Corn.		Total Corn.	Straw and Chaff.
	Quantity.	Weight per Bushel.		
Unmanured (Plot 3)	Bush. Pks.	lbs.	lbs.	lbs.
14 tons Farmyard Manure (Plot 2)	15 3½	61·1	1083	1627
Mineral Manure alone; mean of 2 experiments (Plots 0 and 1)	29 2½	63·6	2049	3094
400 lbs. Ammonia-salts (equal parts Sulphate and Muriate), Plot 10a	18 2½	61·8	1274	1854
200 lbs. Ammonia-salts (equal parts Sulphate and Muriate), and Mineral Manure (Plot 8b)	28 3½	61·9	1966	3070
400 lbs. Ammonia-salts (equal parts Sulphate and Muriate), and Mineral Manure: mean of 12 experiments (Plots 6a, 6b, 11a, 11b, 12a, 12b, 13a, 13b, 14a, 14b, 17a, and 17b)	27 2½	62·6	1863	2830
600 lbs. Ammonia-salts (equal parts Sulphate and Muriate), and Mineral Manure: mean of 4 experiments (Plots 5a, 5b, 16a, and 16b)	31 2½	62·8	2155	3511
400 lbs. Ammonia-salts (equal parts Sulphate and Muriate), Mineral Manure, and 1000 lbs. Rape- cake; mean of 2 experiments (Plots 7a and 7b)	36 3½	63·4	2521	4248
	37 0½	63·0	2528	4444

mental field agreed with the estimates of the wheat-crop over the country generally, in showing the order of the highest grain-yielding quality of the three seasons to have been 1849, 1851, 1850, and that of the highest straw-producing character to have been, on the other hand, 1851, 1850, and 1849. The amount of produce, both corn and straw, was, however, below the average of the 20 years of experiment; though the proportion of corn to straw was fully equal, and the weight per bushel of the grain considerably above the average, these favourable characters being doubtless due to the prevailing dry weather during the maturing and harvest periods.

The season was, upon the whole, pretty favourable for the action of nitrogenous manures, the difference between the produce by ammonia-salts when used alone, and in conjunction with mineral manures, being less than frequently; whilst 600 lbs. of ammonia-salts (with mineral manure), though an excessive amount for the average of seasons, gave not very far short of the same amount of increase of corn for a given quantity of ammonia employed as when only 400 lbs. were used. Both these amounts, however, gave proportionally much less increase than only 200 lbs.

As already explained, and indicated by the few comments made on the results, the arrangement of the manures of the first eight seasons was determined on each year with reference to certain individual points, regard being at the same time paid to the previous manuring and produce of the respective plots, and much more uniformity observed from year to year in the later years. From this time forward, it was sought to bring the whole of the plots still more strictly into comparison one with another, each year, and through a series of years, in order to trace, by the conjoint aid of the field-results and analysis, the relative excess, or deficiency, of the available supply of the different constituents required by the crop, year by year, and through a long course of years. To this end, in the ninth and eleven succeeding years, the manure has been, with a few special exceptions, the same from year to year on the same plot. The only exceptions requiring notice here are, that the manures of Plots 17 and 18 are annually transposed, and that in the sixteenth and succeeding seasons some of the mineral manures were reduced in quantity per acre on all the plots where they had been previously applied.

Appendix Table IX., p. xviii, shows, in a tabular form, the manure applied to each plot, in each of the last 12 years of the experiments; but it will be well to give a more explanatory statement of the description and arrangement of the manures in this place. In doing so the plots will not be enumerated in the same order as in the field, and in the Appendix Tables, but in such as will best indicate the points of comparison which it was sought to establish by the arrangement adopted.

The plan, description, and quantities per acre per annum, for the 12 years (1852-63), were as follows:—

Plot 2.—14 tons farmyard manure (also for the eight preceding years).

Plot 3.—Unmanured (also for the eight preceding years).

Plot 20.—Unmanured (also for five preceding years), duplicate at the other side of the field.

Plot 4.—Unmanured (sulphate of ammonia, and bone-ash acted upon by hydrochloric acid, for seven preceding years).

Plot 0.—Superphosphate of lime alone; composed of 600 lbs. bone-ash and 450 lbs. sulphuric acid, sp: gr: 1·7 (also for three preceding years).

Plot 1.—Mixed alkalis; composed of 600 lbs. sulphate of potass, 400 lbs. sulphate of soda, and 200 lbs. sulphate of magnesia (also for three preceding seasons); reduced to 400, 200, and 200 lbs. respectively, in the sixteenth and succeeding seasons.

Plots 5 (a and b).—Mixed mineral manure; composed of—

300 lbs. sulphate of potass.

200 lbs. sulphate of soda.

100 lbs. sulphate of magnesia.

200 lbs. bone-ash

150 lbs. sulphuric acid, sp: gr. 1·7 } superphosphate of lime.

- In the sixteenth and succeeding seasons the sulphate of potass was reduced to 200 lbs., and the sulphate of soda to 100 lbs.
- Plot 21.—Mixed mineral manure, as Plots 5, and 100 lbs. muriate of ammonia.
- Plot 22.—Mixed mineral manure, as Plots 5, and 100 lbs. sulphate of ammonia.
- Plots 6 (a and b).—Mixed mineral manure, as Plots 5, and 100 lbs. each, sulphate and muriate of ammonia.
- Plots 7 (a and b).—Mixed mineral manure, as Plots 5, and 200 lbs. each, sulphate and muriate of ammonia.
- Plots 8 (a and b).—Mixed mineral manure, as Plots 5, and 300 lbs. each, sulphate and muriate of ammonia.
- Plots 16 (a and b).—Mixed mineral manure, as Plots 5, and 400 lbs. each, sulphate and muriate of ammonia.
- Plots 17 (a and b).—200 lbs. each, sulphate and muriate of ammonia in the ninth and every alternate season; and mixed mineral manure, as Plots 5, in every intermediate season.
- Plots 18 (a and b).—Mixed mineral manure, as Plots 5, in the ninth and every alternate season; and 200 lbs. each, sulphate and muriate of ammonia in every intermediate season.
- Plot 10 a.—200 lbs. each, sulphate and muriate of ammonia (ammonia-salt alone also in the seven preceding seasons, succeeding silicate of potass and superphosphate of lime in the first season).
- Plot 10 b.—200 lbs. each, sulphate and muriate of ammonia (the same in the eighth season, mixed mineral manure in the seventh, ammonia-salts in the sixth, ammonia-salts and mixed mineral manure in the fifth, ammonia-salts in the fourth, unmanured in the third, ammonia-salts in the second, and silicate of potass and superphosphate of lime in the first season).
- Plots 11 (a and b).—200 lbs. each, sulphate and muriate of ammonia, and superphosphate of lime as Plots 5.
- Plots 12 (a and b).—200 lbs. each, sulphate and muriate of ammonia, superphosphate of lime as Plots 5, and 550 lbs. sulphate of soda (reduced to 366 lbs. in the sixteenth and subsequent seasons).
- Plots 13 (a and b).—200 lbs. each, sulphate and muriate of ammonia, superphosphate of lime as Plots 5, and 300 lbs. sulphate of potass (reduced to 200 lbs. in the sixteenth and subsequent seasons).
- Plots 14 (a and b).—200 lbs. each, sulphate and muriate of ammonia, superphosphate of lime as Plots 5, and 420 lbs. sulphate of magnesia (reduced to 280 lbs. in the sixteenth and subsequent seasons).
- Plot 9 a.—550 lbs. nitrate of soda, and mixed mineral manure as Plots 5 (only 475 lbs. nitrate in the ninth, and 275 lbs. in the tenth and eleventh seasons, and no mineral manure in the ninth, tenth, and eleventh seasons, commencing only in the twelfth).
- Plot 9 b.—550 lbs. nitrate of soda alone (only 475 lbs. in the ninth season).
- Plot 15 a.—Mixed mineral manure, as Plots 5 (but with 200 lbs. hydrochloric instead of 150 lbs. sulphuric acid), and 400 lbs. sulphate of ammonia.
- Plot 15 b.—Mixed mineral manure, as Plots 5 (but with 200 lbs.

hydrochloric instead of 150 lbs. sulphuric acid), 800 lbs. sulphate of ammonia, and 500 lbs. rape-cake.
Plot 19.—200 lbs. bone-ash, 200 lbs. hydrochloric acid, 800 lbs. sulphate of ammonia, and 500 lbs. rape-cake.

The sulphates of potass, soda, and ammonia, the muriate of ammonia, and the nitrate of soda, were the ordinary articles of commerce passing under those names; the sulphate of magnesia was Epsom salts. In the following Tables, and discussion, the term "ammonia-salts" will, for brevity, be employed to designate the equal mixture of the sulphate and muriate of ammonia.

The only exception to the above statement of manuring for each of the last 12 years is, that in the first two of them, namely, 1852 and 1853 (and also in the immediately preceding year, 1851), chloride of sodium, or common salt, at the rate of 3 cwts. per acre per annum, was applied to Plot 16 *a*, in addition to the manures enumerated above for that plot.

In the few comments which now follow on the produce of each separate season, with the view of showing the varying effects of one and the same manure according to season, but little reference will be made either to the varying condition of the different plots due to the varying character of the manuring during the preceding eight years, or to that attributable to use of the same manure year after year on the same land; leaving the important question of the limit, or degree, of the effect of accumulation or exhaustion from previous manuring and cropping on the produce of succeeding seasons, for entirely separate consideration further on.

Ninth Season, 1851-52.

October (1851) was, for the most part, fine and mild; November fine, but very cold; December less severe; January and February (1852) mild, with a good deal of rain; March dry and clear, but cold and frosty; April dry, with some hot sun, but a good deal of cold east wind; May variable, but with a good deal of cold east wind; June very wet and cold; July very hot, with several heavy thunderstorms; August, fine at the beginning, very wet in the middle, and fine and hot at the end; September, fine until the 6th, when there was a heavy thunderstorm, with a good deal of rain, the rest of the month being variable, with prevailing low temperatures, but upon the whole not unfavourable. In June the dew-point was below, but the degree of humidity of the air slightly above the average; in July the dew-point was above, but the degree of humidity considerably below the average; and in August and September both dew-point and degree of humidity were notably below the average.

The winter was, therefore, upon the whole, favourable; the

spring dry, cold, and backward; the early summer rainy and cold, and the maturing period variable, with a good deal of hot weather, and some heavy storms.

The wheat-crop was reported to be generally not deficient in bulk, but in many districts much blighted, mildewed, and grown, the result being a yield considerably below the average.

In the following Table is given such a selection of the experimental results as will best illustrate the influence of the season on the productive effects of the different descriptions of manure employed; and all future summaries given to illustrate the characters of the seasons will relate to the produce of the same plots.

TABLE IX.—SUMMARY of the Results of the NINTH SEASON, 1851-2.

MANURES. (Quantities per Acre.)	PRODUCE PER ACRE, &c.				
	Dressed Corn.		Total Corn.	Straw and Chaff.	
	Quantity.	Weight per Bushel.			
Unmanured (Plot 3)	Bush. Pks.	lbs.	lbs.	lbs.	
14 tons Farmyard Manure (Plot 2) .. .r ..	13 3½	56.6	860	1597	
400 lbs. Ammonia-salts alone (Plot 10a)	27 2½	58.2	1716	3457	
Mixed Mineral Manure alone (mean of Plots 5a and 5b)	21 3½	55.9	1320	2787	
Mixed Mineral Manure, and 100 lbs. Ammonia- salts (mean of Plots 21 and 22)	16 3½	57.4	1052	1968	
Mixed Mineral Manure, and 200 lbs. Ammonia- salts (mean of Plots 6a and 6b)	19 2	56.4	1177	2144	
Mixed Mineral Manure, and 400 lbs. Ammonia- salts (mean of Plots 7a and 7b)	20 3½	57.5	1294	2593	
Mixed Mineral Manure, and 600 lbs. Ammonia- salts (mean of Plots 8a and 8b)	26 3	55.9	1629	3811	
Mixed Mineral Manure, and 800 lbs. Ammonia- salts (mean of Plots 16a and 16b)	27 2	55.9	1675	3789	
	28 1½	54.7	1747	4646	

The unmanured produce of grain was the lowest yet obtained, and below the average of the 20 years. The effect of a given amount of ammonia-salts, whether alone or in conjunction with mineral manure, was very much below the average, especially so far as the production of grain was concerned, and where large quantities were used. Even the produce of straw was considerably below the average obtained under like conditions of manuring; but much more so where the small than where the large amounts of ammonia-salts were employed. The weight per bushel of dressed corn was also throughout very low, but especially so in the case of the heavier crops.

Upon the whole, the produce of the experimental field was the worst yet obtained.

Tenth Season, 1852-3.

October and November (1852) were very wet, and, the latter month particularly, very unseasonably warm; December and the first half of January (1853) were also unseasonably mild with a good deal of rain; the rest of January, February, and March, were very cold with a good deal of east and north-east wind, and some snow; April and May were for the most part cold and wet, with the exception of a short period in the middle of each month; June variable, with a good deal of rain and cold wind; the greater part of July was excessively wet with low temperatures, but the end of the month and the beginning of August were fine; the remainder of August and September were dull, unsettled, wet, and cold. Both the dew-point and degree of humidity of the air were generally, and especially the latter, sometimes considerably below the average in June, July, August, and September.

In consequence of the very unfavourable seed-time the breadth of land under wheat was much reduced, and the crop of 1853 was reported to be far inferior to that of any season for many years past.

In the experimental field it was found impossible to work the land, and sow the manures and seed, until February and March, 1853. The following is an abstract of the results obtained from this spring-sown crop:—

TABLE X.—SUMMARY of the Results of the TENTH SEASON, 1852-3.

MANURES. (Quantities per Acre.)	PRODUCE PER ACRE, &c.			
	Dressed Corn.		Total Corn.	Straw and Chaff.
	Quantity.	Weight per Bushel.		
Unmanured (Plot 3)	Bush. Pks.	lbs.	lbs.	lbs.
14 tons Farmyard Manure (Plot 2)	5 3½	45·9	359	1413
400 lbs. Ammonia-salts alone (Plot 10a)	19 0½	51·1	1120	3372
Mixed Mineral Manure alone (mean of Plots 5a and 5b)	9 3½	48·6	642	2049
Mixed Mineral Manure, and 100 lbs. Ammonia- salts (mean of Plots 21 and 22)	10 0½	48·6	599	2040
Mixed Mineral Manure, and 200 lbs. Ammonia- salts (mean of Plots 6a and 6b)	11 2½	49·8	673	2021
Mixed Mineral Manure, and 400 lbs. Ammonia- salts (mean of Plots 7a and 7b)	18 0½	51·5	1030	2788
Mixed Mineral Manure, and 600 lbs. Ammonia- salts (mean of Plots 8a and 8b)	23 2½	52·0	1363	3738
Mixed Mineral Manure, and 800 lbs. Ammonia- salts (mean of Plots 16a and 16b)	23 1½	51·8	1386	3947
	25 0½	52·3	1517	4962

Bad as was the result obtained in the experimental field in 1852, it was very much worse in 1853; indeed, it was, in the latter year, the worst in almost every particular throughout the whole 20 years of the experiments.

Without manure, with farmyard manure, and with the different artificial manures, the produce of grain was considerably less, and the quality worse, than in any other year. The season was very unfavourable for the action of ammonia-salts, especially so far as the production of grain was concerned; though, as in 1852, there was a considerable growth of straw under the influence of the heavier ammoniacal dressings. The weight per bushel of dressed corn was extraordinarily low; being in several instances below, and in none much above 50 lbs.

Eleventh Season, 1853-4.

The latter end of October, and November (1853), were generally favourable; December, and January and February (1854), were upon the whole unusually severe, with a good deal of snow, excepting that the middle and latter part of January, and the end of February, were comparatively mild and fine; March and the greater part of April were very fine, but at the end of the latter month there was unusually severe frost for the period, and a good deal of cold north wind; May was variable, generally cold, and backward, with a good deal of rain; June was generally fine, but cold; the first half of July was also cold with a moderate amount of rain, then came a week or two of fine hot weather, which was succeeded by thunder-storms and heavy rain; the beginning of August was wet, the middle fine though not warm, but the end dry and hot; September was almost throughout fine and favourable for getting in the crops, with high day, though low night temperatures. In June, July, August, and September, the dew-point was below the average; and the degree of humidity of the air was, in June above, in July about, and in August and September below the average.

Upon the whole, then, the period of seed time had been favourable; the winter was unusually severe; the early spring favourable, but succeeded by cold and unseasonable weather until the middle of July, from which time, however, until harvest, the period, though changeable, embraced some fine maturing and harvest weather.

With these characteristics, by no means continuously favourable, the harvest of 1854, though late, was, particularly so far as wheat was concerned, one of the largest yield per acre for many years past.

As the following summary will show, the produce of the experimental field quite bore out this character.

TABLE XI.—SUMMARY of the Results of the ELEVENTH SEASON, 1853-4.

MANURES. (Quantities per Acre.)	PRODUCE PER ACRE, &c.				
	Dressed Corn.		Total Corn.	Straw and Chaff.	
	Quantity.	Weight per Bushel.			
Unmanured (Plot 3)	Bush. Pks.	lbs.	lbs.	lbs.	
14 tons Farmyard Manure (Plot 2)	21 0½	60·6	1359	2137	
400 lbs. Ammonia-salts alone (Plot 10a)	41 0½	62·5	2675	4450	
Mixed Mineral Manure alone (mean of Plots 5a and 5b)	34 1½	60·5	2211	3597	
Mixed Mineral Manure, and 100 lbs. Ammonia-salts (mean of Plots 21 and 22)	24 0½	61·3	1555	2512	
Mixed Mineral Manure, and 200 lbs. Ammonia-salts (mean of Plots 6a and 6b)	31 3½	61·1	2012	3390	
Mixed Mineral Manure, and 400 lbs. Ammonia-salts (mean of Plots 7a and 7b)	34 0½	61·8	2213	3950	
Mixed Mineral Manure, and 600 lbs. Ammonia-salts (mean of Plots 8a and 8b)	45 2	61·8	2947	5550	
Mixed Mineral Manure, and 800 lbs. Ammonia-salts (mean of Plots 16a and 16b)	48 2½	61·6	3137	6126	
	49 8½	61·7	3262	6669	

Thus, the experimental wheat-crop of 1854, the eleventh in succession on the same land, was by far the best hitherto obtained, and nearly the best throughout the 20 years. The weight of grain per acre was generally more than double that of the bad season of 1853 under parallel conditions of manuring: it was about equal to that of 1857; and not far short of that of the extraordinary season just past, 1863. In weight of straw, indeed, the crop of 1854 far exceeded that of 1857, and nearly approached that of 1863. The weight per bushel of dressed corn was also considerably above the average, above that of 1857, and little short of that of 1863. The crop was, then, upon the whole, far above the average in quantity both of corn and straw, and in quality of the former.

The produce of corn per acre by ammonia-salts alone, although it was the tenth year of their application on the same plot without mineral manure, was greater than in any preceding year; and, as will be seen further on, the increase obtained for a given amount of ammonia supplied, was, throughout the plots, considerably more than in the average of seasons. And, notwithstanding the season was so favourable for the action of nitrogenous manures, it was even better than the rival years of 1857 and 1863 for the development of the unmanured, and only mineral-manured crops.

Upon the whole, then, consistently with the character of the crop over the country generally, the experimental wheat-crop of 1854 was as remarkable for superiority in almost every particular, both of quantity and quality, as that of 1853 had been in the opposite direction.

Twelfth Season, 1854-5.

The autumn of 1854 was, upon the whole, fine and seasonable; December, and the first half of January (1855), were fine and generally mild. Then came severe frost and deep snow, and the frost, with occasional snow, rain, and thaw, lasted with more or less severity, through February and March. The beginning and end of April were also cold and frosty, and the month was more or less windy throughout, with dry east winds at the close. May and June were for the most part very cold and dry, with the exception of a short interval in the middle of that period, and the end of June, which was very hot; July was very variable with many fine hot days, but with severe thunder-storms, and, upon the whole, a great excess of rain. The beginning of August was also wet, but the remainder of the month was fine; September also was fine, but cool. In June, August, and September, both the dew-point and the degree of humidity of the atmosphere ranged low, but in July both were somewhat in excess of the average.

Thus, the latter part of the winter, and the early spring, were extremely severe; the remainder of the spring and the early summer cold and dry; July was very variable, with a great deal of rain, and a rather humid atmosphere; but the maturing and harvest periods were more favourable. With these characters of season, the wheat-crop of 1855 was reported to be much less abundant than that of 1854, and the quality very various.

The experimental crops without manure, by farmyard manure, by mineral manure alone, and by mineral manure in conjunction with the smaller amounts of ammonia-salts, were fully equal to the average of the 12 years in amount both of grain and straw; but those grown under the influence of the heavier ammoniacal dressings were below it in both respects. The proportion of corn to straw, and the weight per bushel of dressed corn, were both rather over than under the average of the 12 years. So far as the experimental plots were concerned, therefore, the season of 1855 was of average productiveness with moderate manuring, but it was unfavourable for high manuring, and for the growth and maturation of large crops.

The following Table shows the character of the results obtained in the experimental field:—

TABLE XII.—SUMMARY of the Results of the TWELFTH SEASON, 1854-5.

MANURE. (Quantities per Acre.)	PRODUCE PER ACRE, &c.				
	Dressed Corn.		Total Corn.	Straw and Chaff.	
	Quantity.	Weight per Bushel.			
Unmanured (Plot 3)	Bush. Fks.	lbs.	lbs.	lbs.	
14 tons Farmyard Manure (Plot 2)	17 0	59·2	1072	1787	
400 lbs. Ammonia-salts alone (Plot 10a)	34 2½	62·0	2237	3845	
Mixed Mineral Manure alone (mean of Plots 5a and 5b)	19 3½	57·1	1285	2512	
Mixed Mineral Manure, and 100 lbs. Ammonia-salts (mean of Plots 21 and 22)	18 1½	60·0	1150	1820	
Mixed Mineral Manure, and 200 lbs. Ammonia-salts (mean of Plots 6a and 6b)	24 2½	60·5	1543	2438	
Mixed Mineral Manure, and 400 lbs. Ammonia-salts (mean of Plots 7a and 7b)	28 0	60·6	1782	2937	
Mixed Mineral Manure, and 600 lbs. Ammonia-salts (mean of Plots 8a and 8b)	33 0	59·5	2111	4035	
Mixed Mineral Manure, and 800 lbs. Ammonia-salts (mean of Plots 16a and 16b)	31 2	58·8	2031	4090	
	32 3½	58·2	2108	4763	

Thirteenth Season, 1855-6.

In October (1855) a great deal of rain fell; November was generally fine, but cold. The greater part of December was extremely cold, with severe frosts, some snow, and piercing east winds, but the end of the month was warm. January (1856) was very variable, but, upon the whole, mild, as was also February; March dry and cold, with piercing north-east winds; April and May generally cold, and May particularly very wet; June and July changeable as to temperature, with little rain, and frequently very cold nights until nearly the end of the latter month, which, with the beginning of August, was fine and hot; then came heavy thunder-storms with excessive rain, but the end of August, and the first half of September, were fine, after which again succeeded thunder-storms and heavy rain; and the temperature was generally low throughout the month. The mean dew-point and degree of humidity were above or about the average in June, July, and August, and somewhat below it in September.

Thus, the winter was upon the whole mild; the early spring dry and cold, and the remainder cold and wet; the early summer cold and changeable, then came a short interval of fine and hot weather, succeeded, about the ripening period, by very heavy

rains, and prevailing low temperatures. The harvest period was also generally wet and unfavourable, especially in the later districts.

The extent of land under wheat was reported to be considerably above the average, and shortly before harvest the opinion prevailed that the crop would be of more than average productiveness; but owing to the unfavourable harvest weather a considerable proportion of it was badly got in.

The following results were obtained in the experimental field:—

TABLE XIII.—SUMMARY of the Results of the THIRTEENTH SEASON, 1855-6.

MANURES, (Quantities per Acre.)	PRODUCE PER ACRE, &c.			
	Dressed Corn.		Total Corn.	Straw and Chaff.
	Quantity.	Weight per Bushel.		
Unmanured (Plot 3)	Bush. Pks.	lbs.	lbs.	lbs.
14 tons Farmyard Manure (Plot 2)	14 2	54·8	892	1558
400 lbs. Ammonia-salts alone (Plot 10a)	36 1½	58·6	2277	4317
Mixed Mineral Manure alone (mean of Plots 5a and 5b)	24 0½	55·6	1505	2818
Mixed Mineral Manure, and 100 lbs. Ammonia- salts (mean of Plots 21 and 22)	19 2½	56·8	1207	2067
Mixed Mineral Manure, and 200 lbs. Ammonia- salts (mean of Plots 6a and 6b)	22 1½	57·9	1375	2514
Mixed Mineral Manure, and 400 lbs. Ammonia- salts (mean of Plots 7a and 7b)	27 3	58·3	1736	3072
Mixed Mineral Manure, and 600 lbs. Ammonia- salts (mean of Plots 8a and 8b)	36 3½	57·8	2278	4479
Mixed Mineral Manure, and 800 lbs. Ammonia- salts (mean of Plots 16a and 16b)	39 0	57·0	2454	5136
	37 3½	58·6	2438	5498

The quantity of corn per acre, excepting on the unmanured plot, was fully equal to, and that of the straw rather over, the average of the last 12 of the 20 years. But the crop was unevenly and badly ripened, and the weight per bushel was low. The season was, indeed, not unfavourable to quantity of produce; and, so far, to a fair average productiveness under the influence of liberal manuring; but it was unfavourable for the full development and the maturation of the grain.

Fourteenth Season, 1856-7.

The latter part of October and a great portion of November (1856) were fine and seasonable, but the end of November and beginning of December were unusually severe: then came a short period of very mild weather, with a good deal of rain, followed with fine frosty weather; the quarter having been marked by rapid variations of pressure, and extreme changes of temperature.

In January (1857) there was a good deal of rain, and the greater part of the month was mild; but it became colder, with frost and snow at the end of the month and the beginning of February. The remainder of February, and March, were very dry, with high barometer, frequent sharp frosty nights, and cold easterly winds. In April there was more rain, but also a good deal of fine though cold weather. May was fine, with a good deal of very warm weather, and but little rain. In June there was a good deal of fine and hot weather, but there were also several thunder-storms, with heavy falls of rain, which were much needed, and thoroughly penetrated the soil. During July the weather was generally fine, and occasionally very hot, with much less than the usual amount of rain. In August there were several thunder-storms with heavy rain, but otherwise the weather was fine and remarkably hot. In the early part of September a good deal of rain fell, but the remainder of the month was fine, and its temperature was pretty uniformly rather above the average. In June, July, and August, though the dew-point ranged somewhat high, the temperature did so in a greater degree, so that the atmosphere was drier than usual.

The winter, excepting in the early part, was therefore generally mild; the spring was less so, with a good deal of dry weather, but with a sufficiency of rain in April. The summer was for the most part hot, with a dry atmosphere, but with genial and plentiful rains in June and the beginning of August; and the harvest period was generally favourable.

TABLE XIV.—SUMMARY of the Results of the FOURTEENTH SEASON, 1856-7.

MANURES. (Quantities per Acre.)	PRODUCE PER ACRE, &c.				
	Dressed Corn.		Total Corn.	Straw and Chaff.	
	Quantity.	Weight per Bushel.			
Unmanured (Plot 3)	Bush. Pks.	lbs.	lbs.	lbs.	
14 tons Farmyard Manure (Plot 2)	19 3½	58·8	1236	1577	
400 lbs. Ammonia-salts alone (Plot 10a)	41 0½	60·4	2587	3323	
Mixed Mineral Manure alone (mean of Plots 5a and 5b)	29 0½	58·0	1816	2392	
.. .. .	23 3	58·9	1461	1676	
Mixed Mineral Manure, and 100 lbs. Ammonia- salts (mean of Plots 21 and 22)	23 2½	60·6	1515	1811	
Mixed Mineral Manure, and 200 lbs. Ammonia- salts (mean of Plots 6a and 6b)	35 1½	59·9	2202	2757	
Mixed Mineral Manure, and 400 lbs. Ammonia- salts (mean of Plots 7a and 7b)	44 3½	60·4	2842	3786	
Mixed Mineral Manure, and 600 lbs. Ammonia- salts (mean of Plots 8a and 8b)	48 1	60·7	3094	4374	
Mixed Mineral Manure, and 800 lbs. Ammonia- salts (mean of Plots 16a and 16b)	49 1½	60·5	3163	4693	

The extent of land under wheat was reported to be less than in 1856; but throughout the summer the crop promised extremely well, and after harvest it was estimated to have been unusually productive.

The character of the experimental wheat-crop of 1857 was in many points remarkable, and accorded well with the estimates formed of the crop over the country generally. The amount of gross produce (corn and straw together) fell considerably short of that of either 1854 or 1863, and did not exceed that of several other years of much inferior yield of grain; but the proportion of corn to straw was unusually high, being only surpassed among the experimental seasons in 1854, and about equalled in 1846 and 1849, though in neither of these two years was the amount of produce per acre at all equal to that of 1857. The quantity of straw was, in fact, even below the average, considerably less than the amount of 1854, and still more below that of 1863. But the produce of grain, especially under the influence of high nitrogenous and mineral manuring, was almost identical with that of 1854, the two seasons standing in this respect second only to 1863; whilst, both without manure, and with mixed mineral manure alone, the yield of 1857 even exceeded that of the extraordinary season just passed (1863).

It was, however, especially where the large amounts of ammonia-salts, in conjunction with the mineral manure, were employed, that the tendency to the production of grain rather than of straw was in 1857 so marked, and so much above the average. It is further worthy of remark, that both in 1854, which was the eleventh season, and in 1857, which was the fourteenth season of wheat on the same land, the unmanured produce amounted to about 20 bushels, that by farmyard manure to about 41 bushels, and that by the heaviest artificial manuring to within a fraction of 50 bushels per acre.

Fifteenth Season, 1857-8.

October, November, and December (1857) were, upon the whole, very mild, with unusually little rain during the two latter months. January (1858) was also very dry, and during the last fortnight cold, with north wind and sharp frost. February was also generally cold, with a fair amount of rain, and some snow in the earlier part, and sharp frosts and easterly winds in the latter part of the month. In March there was little rain, but frost, snow, and strong easterly winds in the earlier part of the month. The beginning of April was cold, but most of the remainder fine, and even hot, and a moderate amount of rain fell in the beginning and end of the month; it was also cold in the beginning of May, but fine, dry, and hot towards the end, though with

heavy showers, and about an average fall of rain during the month. June was upon the whole very fine, dry, and hot, with some heavy thunder-showers, but much less than the average amount of rain. In July there was much more rain, and the weather, though variable, was still upon the whole fine and hot. August and September were very fine, with much less than the average fall of rain. Throughout the quarter ending with September, as also in June, the degree of humidity of the atmosphere ranged notably lower than usual.

There was, therefore, during the winter, spring, and summer of 1857-8, upon the whole, much less than the usual amount of rain; though in February, April, May, and July, there were fair amounts. The air was also generally less humid than usual throughout the summer. The temperature, too, was generally above the average throughout the spring and summer months, whilst June was unusually hot.

Early in the summer the appearance of the wheat-plant was generally that of great luxuriance, promising a bulky crop. Owing to the prevailing dry and warm weather of June the harvest was very early, and the months of August and September were favourable both as to dryness and temperature. The reports indicated a crop fully if not above the average, though by no means equal to the extraordinary one of the immediately preceding season.

The following Table shows the character of the results in the experimental field:—

TABLE XV.—SUMMARY of the Results of the FIFTEENTH SEASON, 1857-8.

MANURES (Quantities per Acre.)	PRODUCE PER ACRE, &c.				
	Dressed Corn.		Total Corn.	Straw and Chaff.	
	Quantity.	Weight per Bushel.			
Unmanured (Plot 3)	Bush. Pks.	lbs.	lbs.	lbs.	
14 tons Farmyard Manure (Plot 2)	18 0	60·4	1141	1670	
400 lbs. Ammonia-salts alone (Plot 10a)	38 3½	62·6	2512	3837	
Mixed Mineral Manure alone (mean of Plots 5a and 5b)	22 3½	59·6	1439	2130	
Mixed Mineral Manure, and 100 lbs. Ammonia-salts (mean of Plots 21 and 22)	18 3½	61·4	1207	1588	
Mixed Mineral Manure, and 200 lbs. Ammonia-salts (mean of Plots 6a and 6b)	23 1	61·5	1493	2277	
Mixed Mineral Manure, and 400 lbs. Ammonia-salts (mean of Plots 7a and 7b)	28 3½	61·1	1834	2645	
Mixed Mineral Manure, and 600 lbs. Ammonia-salts (mean of Plots 8a and 8b)	39 0½	62·1	2490	4029	
Mixed Mineral Manure, and 800 lbs. Ammonia-salts (mean of Plots 16a and 16b)	41 3½	61·8	2678	4667	
	41 3½	62·1	2710	4806	

With the moderate dressings the quantity of gross produce per acre (corn and straw together) was rather below the average of the 12 years; but with the higher manuring it was generally equal, and sometimes above it. The quantity of straw was pretty uniformly below the average under parallel conditions of manuring; but the produce of grain was generally above it, and the more so the higher the manuring. The proportion of corn to straw was, therefore, above the average, and the weight per bushel of dressed corn was also rather high.

Thus, so far as the results in the experimental field are concerned, the season of 1858 was, upon the whole, favourable to high proportion and good quality of grain, under the influence of somewhat liberal manuring. There was, however, a very marked decline in the productiveness of a given amount of ammonia where the excessive amounts of it were employed, indicating a somewhat easily reached limit of the productive capabilities of the season.

Sixteenth Season, 1858-9.

During October, November, and the first half of December (1858) there was very little rain, and during November and the early part of December the weather was very cold. The remainder of December, and January and February (1859) were very fine and mild; March was also upon the whole mild, but with more rain; in April, too, a good deal of rain fell, and the latter part of the month was stormy, wet, and cold. May began with cold dry easterly winds, then came a good deal of rain, succeeded by fine and hot weather. During June there were several heavy thunderstorms, a great deal of rain fell, and the air was more humid than usual, though there was also a deal of fine warm weather. July was upon the whole fine and unusually hot, but there were several severe thunderstorms at the beginning and about the middle of the month. August was rather unsettled, but for the most part warm, with a good deal of rain; September was also unsettled, and cold, with an excessive amount of rain. In July the dew point ranged high, but the temperature relatively higher; and throughout the quarter ending with September the degree of humidity of the air was below the average.

Thus, throughout the winter of 1858-9 there was very little rain, and, with the exception of the early part, the weather was very mild. In April there was a full supply of rain, May a deficiency, June a considerable excess, July a moderate amount, August a full, and September an excessive fall; whilst June and July were considerably above the average temperature—July more especially, bringing the wheat rapidly forward; though,

owing to the heavy rains of June, and the bulk of the crop, it was generally much laid. Still, the prospect before harvest was upon the whole good; but the wet and stormy harvest period, and the length of time the crop was out, led to a good deal of injury, especially to the heavier crops, and when got in the yield was estimated to be below the average.

The following results were obtained in the experimental field:—

TABLE XVI.—SUMMARY of the Results of the SIXTEENTH SEASON, 1858-9.

MANURES. (Quantities per Acre.)	PRODUCE PER ACRE, &c.				
	Dressed CORN.		Total CORN.	Straw and Chaff.	
	Quantity.	Weight per Bushel.			
Unmanured (Plot 3)	Bush. Pks.	lbs.	lbs.	lbs.	
14 tons Farmyard Manure (Plot 2)	18 1½	52·5	1051	2175	
400 lbs. Ammonia-salts alone (Plot 10a)	36 0½	56·5	2263	4810	
Mixed Mineral Manure alone (mean of Plots 5a and 5b)	18 3¼	51·5	1207	2730	
Mixed Mineral Manure alone (mean of Plots 5a and 5b)	20 2½	56·0	1275	2358	
Mixed Mineral Manure, and 100 lbs. Ammonia- salts (mean of Plots 21 and 22)	25 1	54·5	1499	3083	
Mixed Mineral Manure, and 200 lbs. Ammonia- salts (mean of Plots 6a and 6b)	29 3¼	56·5	1832	3800	
Mixed Mineral Manure, and 400 lbs. Ammonia- salts (mean of Plots 7a and 7b)	34 2½	55·9	2093	4740	
Mixed Mineral Manure, and 600 lbs. Ammonia- salts (mean of Plots 8a and 8b)	34 2	53·7	2038	5475	
Mixed Mineral Manure, and 800 lbs. Ammonia- salts (mean of Plots 16a and 16b)	34 2½	52·6	2016	5860	

The experimental crops were more than usually bulky wherever the manuring was liberal. With the smaller amounts of ammonia-salts (and mineral manure), the quantity of grain per acre was also slightly above the average; but with the heavy dressings of ammonia there was a considerable deficiency of corn, and a very undue proportion of straw. The weight per bushel of dressed corn was extremely low, though considerably lower with deficient mineral, or excessive nitrogenous manuring. There was less corn by ammonia-salts alone than by mixed mineral manure alone; and even when the ammonia-salts were used in conjunction with mineral manure, there was less corn, though a good deal more straw, from the use of the excessive amounts of 600 lbs. and 800 lbs., than when only 400 lbs. were employed.

It may be observed that this was the first of the years in which there was a reduction of potass and soda in all, and of magnesia in some of the cases, where these bases were formerly supplied.

In this and succeeding seasons the sulphate of potass was in all cases reduced to two-thirds the previous amount; the sulphate of soda to one-half in all cases of the so-called "mixed mineral manure," but only to two-thirds on Plots 12a and 12b. The sulphate of magnesia was, however, not reduced in the "mixed mineral manure," and only by one-third on plots 14a and 14b. Still, wherever potass, soda or magnesia were supplied at all, even the reduced amounts provided more of them annually than was taken off in the crops.

Upon the whole, the season of 1859, with its wet and warm growing and ripening, and wet harvest periods, was one of considerable amount of produce, but of very inferior characters for the formation and maturation of the grain.

Seventeenth Season, 1859-60.

October (1859) was upon the whole wet, the greater part of the month very mild, but the end very cold and frosty; November stormy, cold, and wet; December very cold, windy, and inclement until near the end, which was wet and mild. January (1860) was variable, but generally mild and wet; February very cold, with sharp frost and snow, ending with storms of rain and wind. The greater part of March was cold, with heavy showers and snow; the remainder was finer and warmer. April was very cold, with some snow and sharp frosts; the beginning of May was also cold, but the rest of the month warmer than usual, though very wet. June was very cold and very wet; July also very cold, with a moderate amount of rain, most of which fell after the middle of the month; August cold and very wet, and September also cold, but fine in the early part, though very wet in the latter. In June, July, August, and September, the dew point generally ranged low; but with the unusually low temperatures, the degree of humidity of the air was considerably above the average.

The winter of 1859-60 was thus alternately very cold and very mild, and upon the whole very wet; and the spring, summer, and autumn were very stormy, cold, wet, and unseasonable; indeed, more so than had been known for many years past. The crops were very late, the harvest being two or three weeks later than usual. Wheat was, in some localities, not deficient in bulk, but generally very much damaged, yielding but a small proportion of grain, and that of very low quality. The crop was, indeed, very much below the average both in quantity and quality.

The quantity of grain in the experimental field was generally only about three-fourths that of the average of the 12 years under

equal conditions of manuring; but the deficiency was proportionally less with the heavier dressings. The quantity of straw was also much below the average, though not quite so much so as that of the grain; but, as in the case of the latter, it was proportionally less deficient with the heavier manuring. The quality of grain, as indicated by the weight per bushel of the dressed corn, was throughout extremely low; in fact, lower than in any other year of the 20, excepting 1853.

The following abstract shows the character of the experimental crops:—

TABLE XVII.—SUMMARY of the Results of the SEVENTEENTH SEASON, 1859-60.

MANURES. (Quantities per Acre.)	PRODUCE PER ACRE, &c.				
	Dressed Corn.		Total Corn.	Straw and Chaff.	
	Quantity.	Weight per Bushel.			
Unmanured (Plot 3)	12 3½	52·6	738	1459	
14 tons Farmyard Manure (Plot 2)	32 1½	55·5	1864	3440	
400 lbs. Ammonia-salts alone (Plot 10a)	15 0½	49·5	905	2213	
Mixed Mineral Manure alone (mean of Plots 5a and 5b)	15 3½	53·6	919	1620	
Mixed Mineral Manure, and 100 lbs. Ammonia-salts (mean of Plots 21 and 22)	14 2½	53·2	870	1657	
Mixed Mineral Manure, and 200 lbs. Ammonia-salts (mean of Plots 6a and 6b)	22 0	54·0	1268	2288	
Mixed Mineral Manure, and 400 lbs. Ammonia-salts (mean of plots 7a and 7b)	27 3	54·3	1605	3070	
Mixed Mineral Manure, and 600 lbs. Ammonia-salts, (mean of Plots 8a and 8b)	31 2	52·6	1773	3847	
Mixed Mineral Manure, and 800 lbs. Ammonia-salts (mean of Plots 16a and 16b)	32 2½	51·9	1873	4162	

The experimental crop of the extraordinarily wet and cold growing and ripening season of 1860 was, therefore, in every respect very inferior, and much below the average. In yield of grain it was only about equal in quantity, and it was inferior in quality, to that of 1852, and inferior to it also in produce of straw. But it was superior both in quantity and quality of grain to the miserable crop of 1853, though even inferior to it in weight of straw.

Eighteenth Season, 1860-61.

October (1860) was, upon the whole, seasonable; November was very cold, with a good deal of rain; the beginning of December was mild, but the remainder of the month, and a great

part of January (1861) were extremely severe, many evergreens of long standing being killed during this period. The remainder of January, and February, were much milder, with comparatively little rain. There was, nevertheless, a good deal of cold wind during the latter month, as also pretty continuously through March, April, and the beginning of May, during which periods the rain-fall was below the average. The remainder of May was dry and fine, and even hot. June commenced with cold wind and rain, followed by an interval of fine and hot weather, and then a good deal of rain to the end of the month. July was generally seasonable as to temperature, with less than an average of rain. At the beginning of August some heavy rains fell, but, upon the whole, the month was very dry, fine, and favourable; and the fine weather continued, but with rather low temperature, and a good deal of wind, through the greater part of September, though towards the end of the month a great deal of rain fell. In June, both the dew point and degree of humidity of the air ranged high; but in July, August, and September, they were not far from the average.

The winter of 1860-61 was thus unusually severe, and the autumn-sown wheat-plant was reported to have suffered considerably. The spring of 1861 was generally dry, with a good deal of cold wind; but plentiful rains, and some hot weather, in June, brought the growing crops rapidly forward. July, August, and the greater part of September were, upon the whole, seasonable as to temperature, and degree of humidity of the atmosphere, with less than the usual amount of rain.

The wheat-crop was reported to be generally below the average in quantity per acre, the result being due chiefly to the loss of plant during the winter. It also suffered a good deal from rust, but benefitted much by the favourable weather of the latter part of the summer and of the autumn; fair average, and, in many cases, good quality, compensating somewhat for deficiency of quantity.

In produce of grain per acre, the unmanured, and the deficiently manured plots, were considerably below the average of the 12 years; but the more highly manured ones, though still below, were much more nearly up to the average, and the weight per bushel of dressed corn was throughout rather over the average. The 'produce' of straw was also considerably below the average.

The experimental crop was, therefore, upon the whole, deficient both in quantity of total produce, and yield of grain per acre, but the quality of the latter was fully equal to the average. The crop was, however, in all respects superior to that of 1860;

and, excepting in amount of straw, it was, under the better conditions of manuring, superior to that of 1859 also.

The following is an abstract of the results obtained in the experimental field :—

TABLE XVIII.—SUMMARY of the Results of the EIGHTEENTH SEASON, 1860-61.

MANURE. (Quantities per Acre.)	PRODUCE PER ACRE, &c.			
	Dressed Corn.		Total Corn.	Straw and Chaff.
	Quantity.	Weight per Bushel.		
Unmanured (Plot 3)	Bush. Pks.	lbs.	lbs.	lbs.
14 tons Farmyard Manure (Plot 2)	11 1½	57·4	736	1254
400 lbs. Ammonia-salts alone (Plot 10a)	34 3½	60·5	2202	3101
Mixed Mineral Manure alone (mean of Plots 5a and 5b)	12 3½	55·0	854	1930
15 1½	59·1	1065	1552	
Mixed Mineral Manure, and 100 lbs. Ammonia- salts (mean of Plots 21 and 22)	18 0½	58·4	1208	1799
Mixed Mineral Manure, and 200 lbs. Ammonia- salts (mean of Plots 6a and 6b)	27 2½	59·4	1787	2628
Mixed Mineral Manure, and 400 lbs. Ammonia- salts (mean of Plots 7a and 7b)	34 3½	58·9	2223	3528
Mixed Mineral Manure, and 600 lbs. Ammonia- salts (mean of Plots 8a and 8b)	35 0	58·4	2240	3854
Mixed Mineral Manure, and 800 lbs. Ammonia- salts (mean of Plots 16a and 16b)	37 0	58·3	2385	4383

Nineteenth Season, 1861-62.

October (1861) was generally mild, fine, and dry; November inclement, with an excess of rain, and unusually low temperatures. December was, upon the whole, warmer and drier than usual, but with a good deal of cold wind towards the end. January and February (1862) were, upon the whole, fine and dry, with a good deal of warmer and but little of colder weather than usual. March commenced with frosty weather, but the greater portion of it was unusually wet and mild. April was variable, with some unseasonably cold, but a good deal of warm weather, and a full average amount of rain. May was extremely wet, and, in the early part especially, unusually warm. June, July, and August were almost throughout unsettled, with a good deal of wind and rain, and unusually low temperatures, the nights especially being frequently very cold; and, although the atmosphere contained less than the average actual amount of moisture, with the low temperatures, the degree of humidity was not correspondingly low. September was also variable, with a good deal of rain

at the beginning and end of the month, but with fine and warm weather intermediately.

The winter of 1861-2 was, therefore, upon the whole, mild; but the spring and summer were almost throughout wet, cold, and stormy. The wheat-crop of the country was almost universally reported to be under the average, in many cases root-fallen, and also much mildewed.

The following results were obtained in the experimental field:—

TABLE XIX.—SUMMARY of the Results of the NINETEENTH SEASON, 1861-62.

MANURES. (Quantities per Acre.)	PRODUCE PER ACRE, &c.				
	Dressed Corn.		Total Corn.	Straw and Chaff.	
	--- Quantity.	Weight per Bushel.			
	Bush.	Pks.	lbs.	lbs.	lbs.
Unmanured (Plot 3)	16	0	57·8	996	1713
14 tons Farmyard Manure (Plot 2)	38	1½	61·0	2447	4195
400 lbs. Ammonia-salts alone (Plot 10a)	23	0¼	56·5	1457	2593
Mixed Mineral Manure alone (mean of Plots 5a and 5b)	17	3¼	59·0	1110	1850
Mixed Mineral Manure, and 100 lbs. Ammonia- salts (mean of Plots 21 and 22)	20	1	58·1	1262	2186
Mixed Mineral Manure, and 200 lbs. Ammonia- salts (mean of Plots 6a and 6b)	23	0¾	59·6	1756	2970
Mixed Mineral Manure, and 400 lbs. Ammonia- salts (mean of Plots 7a and 7b)	35	3½	59·4	2333	3910
Mixed Mineral Manure, and 600 lbs. Ammonia- salts (mean of Plots 8a and 8b)	39	1¾	59·2	2465	4679
Mixed Mineral Manure, and 800 lbs. Ammonia- salts (mean of Plots 16a and 16b)	36	1	57·8	2229	4512

The experimental crops, without manure, with farmyard manure, and with the mixed mineral manure in conjunction with all but the most excessive amount of ammonia-salts, were fully equal in amount and quality of grain, and not much deficient in straw, compared with the average of the 12 years. But with mineral manure in conjunction with the very excessive amount of ammonia-salts, the produce of both grain and straw was considerably below the average. Notwithstanding the wetness of the most growing periods of the season, the prevailing low temperatures seem to have been adverse to the production of full amounts of gross produce; but the ripening period seems to have been not so unfavourable to the development of grain where there was moderate luxuriance of growth, and the crop was not too much laid; which, however, according to the reports, was the case

with a considerable proportion of the ordinary wheat-crop of the country.

Twentieth Season, 1862-3.

October (1862) was unusually warm, but with a good deal of wind and rain; November was cold, with comparatively little rain; December, and January and February (1863), were unusually mild, with a fair amount of rain in December and January, and but little in February. March was also upon the whole mild, with but little rain; and wheat showed unusually forward growth. April was very dry and warm. In May there were some refreshing rains, but the temperature was occasionally extremely low, and pretty nearly throughout rather below the average, with frequent storms of wind. The temperature in June was also generally rather below the average, and there was a good deal of rain; which, though needed, and much aiding growth, was so heavy as to lay the most forward and bulky crops. In July there was much less rain than usual, with moderately high day, but low night temperatures, and some sharp night frosts. August, with only moderate temperatures, but less than the usual amount of rain, was upon the whole favourable ripening and harvest weather. In September a good deal of rain fell, and the temperatures ranged rather low. In June, the condition of the atmosphere as to moisture was about the average for that month; but, in July, August, and September, both the actual amount and the degree of humidity were below the average.

With these characters of the season, the reports were almost unanimous that the wheat-crop of 1863 was considerably above the average; and such subsequent experience has proved it to be, both in quantity and quality. Indeed, such a yield, per acre, has not been known for very many years.

It would appear that the extraordinary result was due to almost unchecked growth from the first appearance of the plant above ground up to the time of harvest, rather than to any extraordinary characteristics of season at any one or more particular periods. With the extremely mild winter and early spring, the plant came early forward, and the rains, though sparing upon the whole, came when needed, whilst, though the temperature of the summer was seldom high, it was (if we except the night frosts of July) generally sufficient, and the condition of atmosphere otherwise favourable; so that it may be said that the whole season contributed to a lengthened and almost unbroken course of gradual accumulation.

The following Table shows the character of the results obtained in this extraordinary season, in the experimental field:—

TABLE XX.—SUMMARY of the Results of the TWENTIETH SEASON, 1862–63.

MANURES. (Quantities per Acre.)	PRODUCE PER ACRE, &c.				
	Dressed Corn.		Total Corn.	Straw and Chaff.	
	Quantity.	Weight per Bushel.			
	Bush.	Pks.	lbs.	lbs.	lbs.
Unmanured (Plot 3)	17	1	62·7	1127	1600
14 tons Farmyard Manure (Plot 2)	44	0	63·1	2886	4279
400 lbs. Ammonia-salts alone (Plot 10a)	39	0½	62·6	2587	3481
Mixed Mineral Manure alone (mean of Plots 5a and 5b)	19	2½	63·0	1290	1728
Mixed Mineral Manure, and 100 lbs. Ammonia-salts (mean of Plots 21 and 22)	28	2½	62·4	1852	2588
Mixed Mineral Manure, and 200 lbs. Ammonia-salts (mean of Plots 6a and 6b)	39	2½	62·3	2528	3715
Mixed Mineral Manure, and 400 lbs. Ammonia-salts (mean of Plots 7a and 7b)	53	2½	62·5	3492	5866
Mixed Mineral Manure, and 600 lbs. Ammonia-salts (mean of Plots 8a and 8b)	55	2½	62·3	3614	6602
Mixed Mineral Manure, and 800 lbs. Ammonia-salts (mean of Plots 16a and 16b)	55	3½	62·4	3659	6866

The experimental wheat-crop of 1863, the 20th in succession on the same land, proved to be in quantity of both grain and straw by far the most productive hitherto, and also in quality of grain nearly the best yet obtained. In quantity of straw, or total produce, the crop of 1854 the most nearly approached it; but 1854 and 1857, both of which were years of extraordinary yield, both fell considerably short of 1863 in quantity of grain per acre, and also in quality, as indicated by the weight per bushel.

The season of 1863 was particularly marked by extraordinary productiveness, in both corn and straw, under the influence of a liberal supply of ammonia-salts. Where the quantity applied was not so excessive that the crops were over luxuriant, and much laid by the storms of wind and rain in June, more produce, and especially more corn, was obtained for a given amount of ammonia applied than in any former year of the experiments. Even where the amounts of ammonia-salts were the most excessive, the quantity of both corn and straw per acre was larger than in any preceding season. But, doubtless owing to the heaviest crops having been laid so flat, the amount of increase yielded for each increment of ammonia-salts supplied beyond 400 lbs. per acre

was not so great as in some other seasons. Thus, though in no preceding year had the produce obtained by the mixed mineral manure and the excessive amount of 800 lbs. of ammonia-salts exceeded 50 bushels of dressed corn per acre, that obtained in 1868 by the mixed mineral manure and only 400 lbs. of ammonia-salts was about 53½ bushels, of 62½ lbs. weight per bushel; whilst the mixed mineral manure with 600 lbs. of ammonia-salts, gave scarcely 55½ bushels, and with 800 lbs. scarcely 56 bushels.

Extraordinary as are these amounts of produce, even for good wheat-land cultivated and manured in the ordinary way, they are still more remarkable for the 20th crop of wheat in succession on land of only average wheat-producing quality, which has not been manured with farmyard manure for just a quarter of a century. Nevertheless, there can be no doubt that if the heavier crops had not been so much laid they would have yielded even considerably more. That they did not do so, in a season upon the whole so favourable for the effect of liberal nitrogenous manuring, shows that the higher amounts of ammonia-salts employed were not only excessive for average, but even for unusually favourable seasons.

In conclusion, in regard to these results, it should be observed that whilst the mixed mineral manure and ammonia-salts yielded as much as 55½ bushels of dressed corn, and 6866 lbs. of straw, the same mixed mineral-manure, when used alone, gave scarcely 19½ bushels of dressed corn, and only 1728 lbs. of straw. There was an increase, therefore, due to the action of ammonia-salts, of 36 bushels of dressed corn, and 5138 lbs. of straw. In this fact there is surely striking confirmation of the utter inadequacy of mineral-manures alone to enable the wheat-plant to obtain from the atmosphere a sufficiency of nitrogen for the production of full crops.

No idea is more fixed and prevalent in the farmer's mind than that, after all his labour and money have been expended, he is still at the mercy of the seasons for his reward. The foregoing short abstracts of the results obtained in different seasons, with the few comments made upon them, supply very interesting evidence relating to this point; and Tables XXII.—XXVI., inclusive, in the Appendix, afford the means of studying the subject in much more detail. But the extent of this dependence upon season will be made more strikingly manifest, by placing side by side, at one view, the results obtained by one and the same description and amount of manure in the least favourable, and in the most favourable of the last twelve seasons, during which

the same manure has been applied year after year on the same land. This is done in the following Table:—

TABLE XXI.—SUMMARY of the Results obtained in 1853 and 1863, respectively.

MANURES. (Per Acre, per Annum.)	PRODUCE PER ACRE, &c.							
	Dressed Corn.						Straw and Chaff.	
	Quantity.		Weight per Bushel.					
	1853.	1863.	1853.	1863.	1853.	1863.		
	Bush. Pks.	Bush. Pks.	lbs.	lbs.	lbs.	lbs.		
Unmanured (Plot 3)	5 ½	17 1	45·9	62·7	1413	1600		
14 tone Farmyard Manure (Plot 2)	19 0½	44 0	51·1	63·1	3372	4279		
400 lbs. Ammonia-salts alone (Plot 10a)	9 ¾	39 0½	48·6	62·6	2049	3481		
Mixed Mineral Manure alone (mean of Plots 5a and 5b)	10 0½	19 2½	48·6	63·0	2040	1728		
Mixed Mineral Manure, and 100 lbs. Ammonia- salts (mean of Plots 21 and 22)	11 2½	28 2½	49·8	62·4	2021	2388		
Mixed Mineral Manure, and 200 lbs. Ammonia- salts (mean of Plots 6a and 6b)	18 0½	39 2½	51·5	62·3	2788	3715		
Mixed Mineral Manure, and 400 lbs. Ammonia- salts (mean of Plots 7a and 7b)	23 2½	53 2½	52·0	62·5	3738	5666		
Mixed Mineral Manure, and 600 lbs. Ammonia- salts (mean of Plots 8a and 8b)	23 1½	55 2½	51·8	62·3	3947	6602		
Mixed Mineral Manure, and 800 lbs. Ammonia- salts (mean of Plots 16a and 16b)	25 0½	55 ¾	52·3	62·4	4962	6966		

It should be observed, that although both the quantity and the quality of corn were, under each of the conditions of manuring specified, lower in 1853 than in any other season of the last twelve, and hence the results of that year are selected to contrast with those of 1863, yet the amounts of straw were much lower in some other years. Indeed, the Table shows that in the case of the mixed mineral manure alone the quantity of straw was even higher in 1853 than in 1863. It was, however, in most cases where ammonia-salts were used, one-half, and sometimes in a greater degree, more in 1863 than in 1853. Again, although the quantity of corn obtained was greater in 1863 than in any other year of the twelve wherever ammonia-salts were used, yet, without manure, and with mixed mineral manure alone, it was higher in several other years.

Notwithstanding these exceptions, which are themselves very interesting and significant, the two seasons may still be taken as upon the whole representing, respectively the least and the most favourable of those to which the experiments refer; and the difference in the quantity and quality of the produce obtained by one and the same manure, in the one season compared with the other, is really most striking and instructive. Thus, in 1863 the produce of dressed corn exceeded that of 1853—without manure by 11½ bushels, with farmyard manure by 25 bushels, with 400 lbs.

ammonia-salts alone by $29\frac{1}{2}$ bushels, with mineral manure alone by $9\frac{1}{2}$ bushels; and with mineral manure and ammonia-salts together—with 100 lbs. of ammonia-salts by 17 bushels, with 200 lbs. by $21\frac{1}{2}$ bushels, with 400 lbs. by 30 bushels, with 600 lbs. by $32\frac{1}{2}$ bushels, and with 800 lbs. by $30\frac{1}{2}$ bushels. The difference in quantity was, however, in reality much more than these figures indicate; for whilst the weight of each bushel of dressed corn was in 1863 from 62 to 63 lbs., in 1853 it in no case reached, and in some cases fell far short of, $52\frac{1}{2}$ lbs.

So far as the production of grain was concerned, therefore, the difference of result obtained in the two years was equally striking in point of both quantity and quality.

The important practical question of the amount of ammonia in manure expended for the production of a given amount of increase in one season compared with another, according to the quantity employed, and to the available supply of mineral constituents within the soil, will be made a subject of separate consideration in the Fourth Section of this Report.

The influence of each individual season, and of the extreme seasons, of the twenty, in tending to the development of much or little corn, much or little straw, and high or low quality of grain, under the different conditions of manuring, has now been briefly illustrated; but before leaving the question of the influence of season altogether, and passing to the more exclusive consideration of the effects of the different manures, it is desirable to endeavour to arrive at some conclusion as to whether the later or the earlier seasons were probably on the average the more favourable; so that a proper judgment may be formed as to whether the actual results obtained by the use of any particular description of manure year after year on the same land, may be referred with but a little reservation to the manure employed, or whether they have been, in any material degree, influenced by a progressive or retrogressive character of the seasons of growth.

There is an obvious inappropriateness in attempting to estimate the progressive or retrogressive productiveness of a series of seasons, by reference to the amounts of produce obtained on the application of a particular manure year after year on the same land, when the object of the estimate is to eliminate the influence of season from that due to the exhaustive or accumulative effect of the manure itself.

The annual produce without manure would appear, at first sight, to be the best index of the relative character of the seasons.

On the other hand, it has been seen that those seasons which were the most favourable for the unmanured, or for the merely mineral-manured plots, were not at all the most favourable for those manured highly with nitrogenous manures—that is, for those conditions under which alone large crops could be obtained. Hence, the best season for land in low condition is not the best for land in high condition.

But, by comparing the increasing or diminishing amount of produce from year to year, under very different conditions of manuring, a very fair judgment of the relative character of the earlier and the later seasons can be formed. To this end there are given at one view in Table XXII. (opposite) the average annual produce without manure, with ammonia-salts alone, and with farmyard manure, respectively over the first half, the second half, and the total period of the experiments; and also the average annual produce without manure, with mixed mineral manure alone, with ammonia-salts alone, with ammonia-salts and mixed mineral manure, and with farmyard manure, over the first six, the last six, and the total of the last twelve years of the experiments.

Taking first the whole period of the experiments (twenty years without manure and with farmyard manure, and nineteen with ammonia-salts alone), there is, without manure a slightly, though very slightly, increased annual produce of corn and total produce (though not of straw) over the last half as compared with the first half of the period; with ammonia-salts alone there is a decreased, and with farmyard manure a very much increased, rate of produce in the later years.

Thus, where the crop was simply dependent on the soil and season, the produce was somewhat higher in the later years; where the resources of the soil were overtaxed by the use of a large amount of ammonia-salts every year, the produce diminished; but where an excess of every constituent was annually applied, the crop enormously increased as the experiment proceeded.

Referring to the results obtained over the last twelve years only, the latter half of that period gives, without manure, as much corn, but scarcely as much straw as the former half; with mixed mineral-manure alone (the condition nearest allied to the unmanured) there is a diminution, more particularly in the produce of straw, in the later years; with ammonia-salts alone there is also a diminution, both of corn and straw, but in a somewhat less degree than when the whole period of twenty years is taken into the calculation. With ammonia-salts and mixed mineral manure together, there is a considerable increase of corn, and,

EXPERIMENTS AT ROTHAMSTED ON THE GROWTH OF WHEAT YEAR AFTER YEAR
ON THE SAME LAND.

TABLE XXII.—ANNUAL AVERAGE PRODUCE, &c., over the First half, the Second half, and the Total periods of the application of different Manures, each Year after Year on the same Land.

Plot		AVERAGE ANNUAL.			Duration of Total Period.
		First half of Period.	Second half of Period.	Total Period.	
Dressed Corn, per Acre, in Bushels and Pecks.					
3	Unmanured, every year	15 2½	16 2½	16 1	20 years—1844-1863.
10a	Ammonia-salts alone, every year	24 3½	23 3½	24 1½	
2	14 tons Farmyard Manure, every year	27 0½	37 3½	32 1½	
3	Unmanured, every year	15 1½	15 2	15 2	12 years—1852-1863.
5	Mixed Mineral Manure alone, every year	18 3½	18 0½	18 1½	
10a	Ammonia-salts alone, every year	22 1	22 0	22 2½	
7	Ammonia-salts and Mixed Mineral Manure, every year	35 0½	37 2½	36 1½	
2	14 tons Farmyard Manure, every year	33 1½	37 1½	35 1½	
Weight per Bushel of Dressed Corn, in lbs.					
3	Unmanured, every year	58.2	57.6	57.9	20 years—1844-1863.
10a	Ammonia-salts alone, every year	58.7	56.6	57.6	
2	14 tons Farmyard Manure, every year	59.8	60.8	60.0	
3	Unmanured, every year	55.8	57.2	56.5	12 years—1852-1863.
5	Mixed Mineral Manure alone, every year	57.1	58.7	57.9	
10a	Ammonia-salts alone, every year	55.9	56.8	55.9	
7	Ammonia-salts and Mixed Mineral Manure, every year	57.9	58.9	58.4	
2	14 tons Farmyard Manure, every year	56.8	59.8	59.3	
Total Corn, per Acre, in lbs.					
3	Unmanured, every year	1018	1085	1026	20 years—1844-1863.
10a	Ammonia-salts alone, every year	1628	1627	1575	
2	14 tons Farmyard Manure, every year	1757	2395	2076	
3	Unmanured, every year	968	965	964	12 years—1852-1863.
5	Mixed Mineral Manure alone, every year	1171	1144	1157	
10a	Ammonia-salts alone, every year	1468	1408	1435	
7	Ammonia-salts and Mixed Mineral Manure, every year	2195	2356	2276	
2	14 tons Farmyard Manure, every year	2102	2362	2232	
Total Straw (and Chaff), per Acre, in lbs.					
3	Unmanured, every year	1698	1693	1693	20 years—1844-1863.
10a	Ammonia-salts alone, every year	2846	2640	2737	
2	14 tons Farmyard Manure, every year	3071	3860	3515	
3	Unmanured, every year	1678	1645	1662	12 years—1852-1863.
5	Mixed Mineral Manure alone, every year	2012	1783	1898	
10a	Ammonia-salts alone, every year	2693	2513	2603	
7	Ammonia-salts and Mixed Mineral Manure, every year	4833	4190	4212	
2	14 tons Farmyard Manure, every year	3794	3944	3869	
Total Produce (Corn and Straw), per Acre, in lbs.					
3	Unmanured, every year	2711	2728	2719	20 years—1844-1863.
10a	Ammonia-salts alone, every year	4474	4166	4312	
2	14 tons Farmyard Manure, every year	4828	6355	5591	
3	Unmanured, every year	2641	2610	2626	12 years—1852-1863.
5	Mixed Mineral Manure alone, every year	3183	2927	3055	
10a	Ammonia-salts alone, every year	4156	3921	4038	
7	Ammonia-salts and Mixed Mineral Manure, every year	6428	6646	6487	
2	14 tons Farmyard Manure, every year	5896	6306	6101	

though a diminution in the produce of straw, still some increase of total produce, during the later years. Finally, with farmyard-manure there is an increase of both corn and straw in the latter as compared with the former half of the twelve years, but in a much less degree than over the last ten as compared with the first ten years of the whole period of the experiments.

The general result over the final twelve years is, then, that the average annual yield was, without manure, much the same over the whole period; that, notwithstanding the exhausting effects of applying ammonia-salts every year, the annual diminution of produce under their influence was proportionally less during the latter half of the last twelve, than of the whole nineteen years of their use; that where ammonia-salts and all mineral constituents, except silica, were liberally supplied every year, the produce of corn increased, and that of the straw somewhat diminished; lastly, that where an excess of every constituent required by the crop was annually applied, as in the farmyard manure, the rate of increase from year to year was not so great during the later as during some of the earlier years.

That the unmanured produce should keep up its yield during the later years, and that the produce by the exhaustive process of applying ammonia-salts every year should diminish less during the latter half of the twelve than of the whole nineteen years, seems sufficient indication that the later seasons of the experiments were, upon the whole, more favourable than the earlier ones. But to this evidence may be added that derivable from the fact, that although the average weight per bushel of dressed corn without manure, and with ammonia-salts alone, was considerably less during the latter than during the earlier half of the whole period, it was, nevertheless, without manure considerably higher, and with ammonia-salts alone about as high, during the latter as during the earlier half of the last twelve years. It is, therefore, clear, that even under the most defective soil conditions the crop has either not deteriorated, or has done so in a less degree, in the later years.

Upon the whole, then, it must be concluded, that the later years of the experimental period were, on the average, slightly more favourable to the crop than the earlier ones. Assuming this to have been the case, it must be admitted, that the fact of the unmanured plot maintaining its produce throughout the whole twenty years is probably in some degree due to the better average of the seasons themselves in the later years; and, consequently, that had it been otherwise, the unmanured produce would have shown some slight decline in the later years, or rather, some slight

excess in the earlier ones, due to the accumulation of many previous courses of manuring and cropping.

These few illustrations will serve to indicate the degree, or limit, of the influence of any slight progressive improvement in the character of the seasons of the experimental period, and thus prepare the way for considering the effects of accumulation, or exhaustion, of constituents, from the manuring and cropping of preceding, on the produce of succeeding years.

II. EFFECTS OF THE UNEXHAUSTED RESIDUE FROM PREVIOUS MANURING UPON SUCCEEDING CROPS.

WHEN the same crop has been grown for many years in succession on the same land, in some cases with a change of manures, and in others with the same manure year after year, it is obviously essential to a right interpretation of the results obtained, carefully to consider the effects of the unexhausted residue from previous manuring upon the succeeding crops. The questions of the permanency of effect of different manures, and of the tendency to exhaustion which partial manuring may induce, are, moreover, of great practical importance, and are frequently discussed by practical men.

These questions cannot, however, be satisfactorily dealt with without such evidence as the accurate record of the amounts of produce obtained year after year, on the application of manures of known description and amount, can alone afford. The results of the experiments which form the subject of this Report obviously provide data well fitted to aid the elucidation of some of the important points involved. The subject is necessarily one of detail, requiring analytical as well as field results for its full consideration; but it will be here treated of by reference to the field results alone, and only so far as may be necessary to aid the proper interpretation of the results themselves, and to give some indication of their bearings upon the important practical questions—on the one hand of accumulation, and on the other of exhaustion.

The results first adduced will illustrate more particularly the effects upon succeeding crops of an accumulated residue from previous nitrogenous manuring.

In the first year of the 20 of the experiments, plot 4 was manured with the ashes of farmyard-dung, and gave no increase of produce whatever; during the next 7 years it was manured with superphosphate of lime and sulphate of ammonia, the latter in amount averaging about 277 lbs. per acre per annum; and throughout the subsequent 12 years it received no manure whatever. Table XXIII. shows the produce and increase obtained during the 7 years of the application of the artificial manures,

and also during the succeeding 12 years under the influence of the previous heavy cropping, and of the unexhausted residue of the previous mineral and ammoniacal manuring:—

TABLE XXIII.—PRODUCE and INCREASE of WHEAT obtained during 7 Years of the application of Phosphatic and Ammoniacal Manure, and during the 12 succeeding Years without Manure.

Plots.	MANURES, &c.	7 Years, Manured. 1845—1851.		12 Years, Unmanured. 1852—1863.	
		Total.	Average Annual.	Total.	Average Annual.
Dressed Corn, per Acre ; in Bushels and Pecks.					
4	Superphosphate of Lime, & Sulphate of Ammonia, annually, for 7 years)	193 0	27 2½	203 1½	16 3½
3	Continuously unmanured	123 2½	17 2½	185 3½	15 2
	Increase	69 1½	9 3½	17 2½	1 1½
Weight per Bushel of dressed Corn, lbs.					
4	Superphosphate of Lime, & Sulphate of Ammonia, annually, for 7 years)	..	61·2	..	57·2
3	Continuously unmanured .. ..	..	60·2	..	56·5
	Difference .. ..	..	1·0	..	0·7
Total Corn, per Acre ; lbs.					
4	Superphosphate of Lime, & Sulphate of Ammonia, annually, for 7 years)	12,786	1827	12,858	1072
3	Continuously unmanured	8,037	1148	11,567	964
	Increase	4,749	679	1,291	108
Total Straw (and Chaff), per Acre ; lbs.					
4	Superphosphate of Lime, & Sulphate of Ammonia, annually, for 7 years)	20,620	2946	20,783	1732
3	Continuously unmanured	12,799	1828	19,940	1662
	Increase	7,821	1118	843	70
Total Produce (Corn and Straw), per Acre ; lbs.					
4	Superphosphate of Lime, & Sulphate of Ammonia, annually, for 7 years)	33,406	4773	33,641	2804
3	Continuously unmanured	20,836	2976	31,507	2626
	Increase	12,570	1797	2,134	178

After the ashes of farmyard-dung had been used without giving any increase, the phosphatic and ammoniacal manuring gave, during the 7 years of its application, a total increase of about 69½ bushels of dressed corn, and 7821 lbs. of straw; or an average annual increase of nearly 10 bushels of dressed corn, and 1118 lbs., or about half a ton of straw. These amounts would remove from the land only about one-third of the nitrogen, and one-seventh of the phosphoric acid supplied in the manure; to say nothing of the phosphoric acid, and all other mineral constituents, supplied in the first year of the experiments (1843-4) in the form of the ashes of farmyard-dung. Yet the total amount of increase obtained during the next 12 years, due to the large residue from the previous manuring, was only 17½ bushels of corn, and 843 lbs. of straw, or of corn about one-fourth and of straw about one-ninth as much as that yielded during the seven years of the application of the phosphate and ammonia. The average annual increase over the 12 years amounted to less than 1½ bushel of dressed corn and to 70 lbs. of straw.

This experiment was arranged for the purpose of determining whether during the later years there would be a less produce than on the continuously unmanured plot, indicating exhaustion of the available alkalies and silica during the 7 years of forcing by the application of other constituents to their exclusion; or whether there would be an increase, due to the accumulation in the soil of nitrogen and phosphoric acid, in which case it might be concluded that there was, as yet, no deficiency of available alkalies and silica in the soil, relatively to the annually available supplies of nitrogen from natural sources. The latter proved to be the case. In fact, there is no doubt that the farmyard manure ashes applied in the first year, would supply at any rate considerably more potass than was removed by the increased produce during the next 7 years. It will perhaps be objected, that the increase would have been much greater, both during and after the 7 years, had fresh supplies of alkalies been provided. Under the conditions of the experiment, such as they were, however, the unexhausted residue of previous manuring was obviously very slowly available in succeeding seasons.

Again, to a portion of the experimental plot 3, from which 12 unmanured crops of wheat had been taken—a kind of treatment which it has been alleged by Baron Liebig would bring our soil into such a condition of exhaustion of available mineral constituents that it would yield no increase on the application of ammonia-salts alone—a dressing of these salts was applied in the 13th season, and then 7 crops were taken without further manure, in order to trace the degree or limit of the effect of the unex-

hausted residue of nitrogen supplied. The results are given in the following Table (XXIV.):—

TABLE XXIV.—PRODUCE and INCREASE of WHEAT, both in the Year of Application, and during the 7 succeeding Years, by the use of Ammonia-salts alone for 1 Year after 12 Crops without Manure.

Plots.	MANURES, &c.	1 Year, Manured (after 12 Unma- nured). 1856.	Total, 7 Years Unma- nured. 1857— 1863.
Dressed Corn, per Acre; in Bushels and Pecks.			
3a	400 lbs. Ammonia-salts for 1856, afterwards unmanured	28 0 $\frac{3}{4}$	115 0 $\frac{3}{4}$
3	Continuously unmanured	14 2	113 2 $\frac{3}{4}$
	Increase by Ammonia-salts	13 2 $\frac{3}{4}$	1 2
Weight per Bushel of Dressed Corn; lbs.			
3a	400 lbs. Ammonia-salts for 1856, afterwards unmanured	56·3	..
3	Continuously unmanured	54·3	..
	Increase by Ammonia-salts	2·0	..
Total Corn, per Acre; lbs.			
3a	400 lbs. Ammonia-salts for 1856, afterwards unmanured	1759	7138
3	Continuously unmanured	892	7025
	Increase by Ammonia-salts	867	113
Total Straw (and Chaff), per Acre; lbs.			
3a	400 lbs. Ammonia-salts for 1856, afterwards unmanured	3052	11,836
3	Continuously unmanured	1558	11,448
	Increase by Ammonia-salts	1494	388
Total Produce (Corn and Straw), per Acre; lbs.			
3a	400 lbs. Ammonia-salts for 1856, afterwards unmanured	4811	18,974
3	Continuously unmanured	2450	18,473
	Increase by Ammonia-salts	2361	501

Thus, 400 lbs. of ammonia-salts per acre, applied on land which had grown turnips, barley, peas, wheat, and oats since manuring, and then 12 crops of wheat without manure, and applied, moreover, in a season of inferior grain-producing quality, gave in the year of the application an increase of about $13\frac{1}{2}$ bushels of dressed corn, and 1494 lbs. or rather more than $13\frac{1}{2}$ cwts. of straw. This amount of increase would, however, carry off only about one-fourth of the nitrogen supplied. Yet the total increase obtained without further manure during the 7 succeeding years, was only $1\frac{1}{2}$ bushel of dressed corn, and 388 lbs., or about $3\frac{1}{2}$ cwts., of straw. Here again, then, the residue of the previous nitrogenous manuring was but very slowly, and very partially, recovered in the succeeding crops.

It may, of course, be alleged against this experiment, that the want of effect of the residue of the previous nitrogenous manuring was due to the exhaustion of mineral constituents. The experiment next considered is less open to this objection.

Plot 5 was variously, but liberally, manured during the first 8 years of the experiments. During that period, considerably more nitrogen, more than twice as much potass and phosphoric acid, and probably more of every other mineral constituent, except silica, had been applied in the manures than was taken off in the total produce; and very much more, therefore, than was contained in the increase of produce. In each of the 12 succeeding years, a mixed mineral manure, supplying liberally potass, soda, magnesia, lime, sulphuric acid, and phosphoric acid (but no silica), was applied. Table XXV. (over leaf) shows the results obtained during these 12 years.

It is seen that the total increase obtained during 12 years by the annual use of a liberal mixed mineral manure, succeeding 8 years of accumulation of nitrogen and mineral constituents, was only about $35\frac{1}{2}$ bushels of dressed corn, and 2827 lbs., or about $25\frac{1}{2}$ cwts. of straw; equal to an average annual increase of less than 3 bushels of dressed corn, and little more than 2 cwts. of straw.

The question arises—is this amount of increase due to the mineral manures applied during the 12 years of its production, or is the whole, or part of it, to be attributed to the previous accumulation? Doubtless part is due to previous accumulation, and part only to the direct effect of the newly-supplied mineral manure in enabling the plant to avail itself more fully of the natural supplies of the soil and season. Even were nearly the whole attributable to accumulation of nitrogen previously supplied, the amount is very small compared with that from direct nitrogenous manure. In fact, the limit of the effect of the unexhausted residue from the nitrogenous manuring of the earlier years

TABLE XXV.—PRODUCE and INCREASE of WHEAT obtained during 12 Years with Mixed Mineral Manure, after 8 Years of liberal Nitrogenous and Mineral Manuring.

Plots.	MANURES, &c. :	12 Years, 1852—1863.	
		Total.	Average Annual.
Dressed Corn, per Acre ; in Bushels and Pecks.			
5	Mixed Mineral Manure alone, every year	221 0 $\frac{1}{2}$	18 1 $\frac{1}{2}$
3	Unmanured, every year	185 3 $\frac{1}{2}$	15 2
	Increase	35 1 $\frac{1}{2}$	2 3 $\frac{1}{2}$
Weight per Bushel of Dressed Corn ; lbs.			
5	Mixed Mineral Manure alone, every year .. .. .	..	57·9
3	Unmanured, every year .. .. .	..	56·5
	Increase .. .. .	..	1·4
Total Corn, per Acre ; lbs.			
5	Mixed Mineral Manure alone, every year	13,888	1157
3	Unmanured, every year	11,567	964
	Increase	2,321	193
Total Straw (and Chaff), per Acre ; lbs.			
5	Mixed Mineral Manure alone, every year	22,767	1897
3	Unmanured, every year	19,940	1662
	Increase	2,827	235
Total Produce (Corn and Straw), per Acre ; lbs.			
5	Mixed Mineral Manure alone, every year	36,655	3054
3	Unmanured, every year	31,507	2626
	Increase	5,148	428

is seen to be such, that it is obvious the average results of the different manures over the last 12 years, may, in most cases, be

taken as sufficiently nearly indicating their comparative effects in a practical point of view.

If, however, the increase on plot 5 during the 12 years is to be referred in any great part to previous accumulation, what an insignificant amount remains as the effect of the mixed mineral manure in restoring the productiveness of the wheat-exhausted soil. It will, perhaps, be said that it would have been greater if silica in an available form had also been supplied. Baron Liebig has, however, maintained that, provided there be a sufficiency of available alkali in the soil, there will never be a deficiency of available silica. Our own analytical results do not justify this conclusion in all its fulness. At the same time, it may be stated that the mixed mineral manure employed did supply a great excess of available alkali; and that when to the same mineral manure 400 lbs. of ammonia-salts were annually added there was a further annual increase of nearly 18 bushels of dressed corn, and nearly 20½ cwt. of straw, notwithstanding the exclusion of silica from the manure.

The next selection of results affords even more direct and more striking evidence of the comparatively small immediate effects of the supposed unexhausted residue from previous nitrogenous manuring.

During the first 8 years of the experiments, plots 17 and 18 received much about the same amounts of nitrogen, potass, and phosphoric acid, and yielded about the same amounts of total produce as plot 5; plot 18, however, received rather less than the others. The accumulation of nitrogen and mineral constituents was, in fact, practically very nearly the same on all 3 plots. From this time, instead of receiving mineral manure every year as plot 5, each of the other two plots (17 and 18) received ammonia-salts and mixed mineral manures alternately. In other words, when plot 17 was manured with ammonia-salts, plot 18 was manured with the mixed mineral manure, and *vice versa*; so that, each year, the one had ammonia-salts immediately succeeding the mixed mineral manure, and the other the mixed mineral manure immediately succeeding ammonia-salts. The detailed results of this most interesting experiment are recorded in the Appendix Tables, and some of them are exhibited in the coloured diagram No. II. (facing p. 69), to which reference will be made further on. But the point to which attention is now to be particularly directed is the amount of increase obtained when the mixed mineral manure each year succeeded ammonia-salts, as on plots 17 or 18, compared with that obtained when the same mixed mineral manure was employed year after year on the same plot, as on plot 5. Table XXVI, illustrates this point:—

64 *Report of Experiments on the Growth of Wheat.*

TABLE XXVI.—PRODUCE of WHEAT by Mixed Mineral Manure each Year succeeding Ammonia-salts, compared with that by Mixed Mineral Manure Year after Year.

Plots.	MANURES, &c.	12 Years, 1852—1863.	
		Total.	Average Annual.

Dressed Corn, per Acre; in Bushels and Pecks.

17 or 18	Mixed Mineral Manure, each year succeeding } 400 lbs. Ammonia-salts }	225 3 $\frac{1}{4}$	18 3 $\frac{1}{4}$
5	Mixed Mineral Manure, every year	221 0 $\frac{3}{4}$	18 1 $\frac{3}{4}$
	Increase	4 2 $\frac{1}{4}$	0 1 $\frac{1}{2}$

Weight per Bushel of Dressed Corn; lbs.

17 or 18	Mixed Mineral Manure, each year succeeding } 400 lbs. Ammonia-salts }	..	58·0
5	Mixed Mineral Manure, every year .. .. .	..	57·9
	Increase .. .. .	..	0·1

Total Corn, per Acre; lbs.

17 or 18	Mixed Mineral Manure, each year succeeding } 400 lbs. Ammonia-salts }	14,177	1181
5	Mixed Mineral Manure, every year	13,888	1157
	Increase	289	24

Total Straw (and Chaff), per Acre; lbs.

17 or 18	Mixed Mineral Manure, each year succeeding } 400 lbs. Ammonia-salts }	23,823	1985
5	Mixed Mineral Manure, every year	22,767	1897
	Increase	1,056	88

Total Produce (Corn and Straw), per Acre; lbs.

17 or 18	Mixed Mineral Manure, each year succeeding } 400 lbs. Ammonia-salts }	£8,000	3166
5	Mixed Mineral Manure, every year	36,655	3054
	Increase	1,345	112

Assuming, as doubtless was the case, that at the commencement the 3 plots were practically in very nearly the same condition of productiveness, it might be supposed that the mixed mineral manure applied each year after ammonia-salts, as on plots 17 or 18, thus providing the most favourable conditions for the productive effect of the unexhausted nitrogenous residue, would give a considerable increase beyond that on plot 5, where the mineral manure each year succeeded mineral manure. Table XXVI. shows, however, that plots 17 or 18 gave annually only about $\frac{1}{4}$ bushel of corn, and $\frac{3}{4}$ cwt. of straw more than plot 5. Yet the average increase obtained in the years of the application of the ammonia-salts on plots 17 or 18, though always succeeding the mineral manure, would carry off little more than one-third of the nitrogen supplied; whilst, as the next Table (XXVII., p. 66) shows, this increase was considerably less than when the ammonia-salts were used in conjunction with, instead of in succession to, the mixed mineral manure.

Thus, in the course of 12 years, an annual supply of 400 lbs. of ammonia-salts, each year succeeding the mixed mineral manure, gave 45 bushels less corn, and 5475 lbs., or nearly 49 cwts., less straw, than the same amount of ammonia-salts used each year in conjunction with the mixed mineral manure—being an average annual deficiency of about $3\frac{1}{2}$ bushels of corn, and rather more than 4 cwts. of straw, where the ammonia-salts were used in the year after, instead of with the mineral manure. Even adding the average annual increase (over the unmanured produce) by the ammonia-salts succeeding the mineral manure, to that by the mineral manure succeeding the ammonia-salts, the amount scarcely reaches that obtained where the two manures were used in conjunction. That is to say, the influence of the mineral manure succeeding the ammonia-salts seems to have been to render practically available, at any rate no more of the unrecovered residue of the supplied nitrogen than brought up the increase in two years to that attainable in the one year when the two manures were used together, the whole of the remainder being still unaccounted for, so far as the immediate increase of crop is concerned.

The facts brought to view in the last five Tables (XXIII.—XXVII.), are of great scientific interest, and of great practical importance.

It has been alleged by Baron Liebig that, in some of our experiments, there has been so much more nitrogen annually applied in manure than taken off in the increase of crop, that after a few years the increase obtained on a further addition was not at all due to the new supply, but would have been the same without it,

TABLE XXVII.—PRODUCE OF WHEAT by Ammonia-salts each Year in conjunction with the Mixed Mineral Manure, compared with that by Ammonia-salts each Year succeeding the Mixed Mineral Manure.

Plots. ¹	MANURES, &c.	12 Years, 1832—1863.	
		Total.	Average Annual.
Dressed Corn, per Acre ; in Bushels and Pecks.			
7	400 lbs. Ammonia-salts and Mixed Mineral Manure, every year	436 2	36 1½
17 or 18	400 lbs. Ammonia-salts, each year succeeding Mixed Mineral Manure	391 1½	32 2½
	Difference	45 0½	3 3
Weight per Bushel of Dressed Corn ; lbs.			
7	400 lbs. Ammonia-salts and Mixed Mineral Manure, every year .. .. .	..	58·4
17 or 18	400 lbs. Ammonia-salts, each year succeeding Mixed Mineral Manure .. .. .	..	58·7
	Difference .. .. .	..	0·3
Total Corn, per Acre ; lbs.			
7	400 lbs. Ammonia-salts and Mixed Mineral Manure, every year	27,306	2275
17 or 18	400 lbs. Ammonia-salts, each year succeeding Mixed Mineral Manure	24,652	2054
	Difference	2,654	221
Total Straw (and Chaff), per Acre ; lbs.			
7	400 lbs. Ammonia-salts and Mixed Mineral Manure, every year	50,539	4212
17 or 18	400 lbs. Ammonia-salts, each year succeeding Mixed Mineral Manure	45,064	3755
	Difference	5,475	457
Total Produce (Corn and Straw), per Acre ; lbs.			
7	400 lbs. Ammonia-salts and Mixed Mineral Manure, every year	77,845	6487·
17 or 18	400 lbs. Ammonia-salts, each year succeeding Mixed Mineral Manure	69,716	5869
	Difference	8,129	678

by virtue of the large accumulation within the soil from the previous manuring. The results adduced show that there is no foundation in fact for this assumption.

It is demonstrated that, of the nitrogen supplied in manure for wheat, and not removed in the immediate increase of crop, so much as remains in the soil is in such a state of combination, or distribution, as to be extremely slowly recoverable by succeeding crops of the same description. How far such residue would be more rapidly available to a succession of crops of different descriptions, taking different ranges within the soil, and having different habits, and requiring different conditions, of growth in other respects, is a very important question, both in a scientific and practical point of view. It would be impossible to consider adequately in this place the evidence in our possession bearing upon this point; but it may be remarked, in passing, that it is in favour of the supposition that other plants grown in alternation with the cereals do gather up, within a given time, more of the nitrogen supplied for, but unused by, the latter, than a succession of them would do; and even barley seems capable of utilizing, within a given time, a much larger proportion of the nitrogen of manure not recovered in the immediate increase of the crop than wheat.

Although the excess of the nitrogen supplied in the manure beyond that taken off in the increase of the crop for which it was applied had such little influence upon the next succeeding crop, analysis of the soils from several of the experimental plots has shown that there is an accumulation of nitrogen in some form. Nor can there be any doubt that, except in special cases, soils become richer rather than poorer in nitrogen in the course of cultivation; showing a gradual accumulation of nitrogen beyond that annually available for the crops. In illustration, it is sufficient to refer to the fact, that the percentage of nitrogen in surface-soils is found to be much higher than in the subsoils on which they rest; that is to say, it is the higher the more they are exposed to the contact of the roots, the débris of the crops, the manure, and the atmosphere.

Leaving out of consideration the question whether or not there is an actual loss of a portion of the nitrogen supplied in the manure, either through the agency of the growing plant, or from the transformation of nitrogenous compounds within the soil, and evaporation in some form, or drainage beyond the reach of the roots, the obvious practical conclusion from the results hitherto adduced in this Section is, that, of the nitrogen supplied in manure for the growth of wheat, a large proportion remains unrecovered as increased yield in the immediate crop, and

is but very slowly, if ever fully, recovered in succeeding crops.

The next question to consider is, the degree, or limit, of effect on succeeding crops, of the unexhausted residue of *mineral* manures. This point is illustrated in a very interesting manner in the coloured diagrams (I. and II.) facing p. 69.

The results obtained on plots 3, 10*a*, and 10*b*, to which diagram I. relates, will be first noticed. The diagram, which will be easily understood on inspection, shows at one view the general character of the manuring, and the bushels of corn obtained per acre, on each of the plots, in each of the 20 years of the experiments (harvests 1844-1863 inclusive); and the following is a more detailed description of the experiments and their results:—

Plot 3 was unmanured throughout the 20 years, and during several previous seasons.

Plots 10*a* and 10*b* had the same mineral manure in the first year (1843-4). 10*a* had ammonia-salts in each of the 19 succeeding years. 10*b* had the same amounts of ammonia-salts in 17 out of the 19 years; in the 3rd year of the experiments (1846) it was left unmanured, in the 5th (1848) it had mixed mineral manure with the ammonia-salts, and in the 7th (1850) mixed mineral manure alone.

The following Table shows the total amounts of the different manures applied per acre on each of the two plots (10*a* and 10*b*) during the 19 years, 1845-1863 inclusive:—

TABLE XXVIII.

	Plot 10 <i>a</i> .	Plot 10 <i>b</i> .	10 <i>a</i> over or under 10 <i>b</i> .
	lbs.	lbs.	lbs.
Sulphate of Ammonia	3692	3268	+ 424
Muriate of Ammonia	3468	3268	+ 200
Bone-ash .. .. .	..	400	- 400
Sulphuric Acid (Sp. gr. 1.7) .. .. .	..	300	- 300
Pearl-ash .. .. .	..	600	- 600
Soda-ash .. .. .	..	400	- 400
Sulphate of Magnesia .. .. .	..	200	- 200

In the 1st year (1843-4), although the land was in that state of practical exhaustion consequent on the removal of turnips, barley, peas, wheat, and oats since the last application of farmyard-manure, plots 10*a* and 10*b*, manured with silicate of potass and superphosphate of lime, gave less than half a bushel of dressed corn, and only 77 lbs. of total produce more, per acre, than the unmanured plot (3).

THE
JOURNAL
OF
THE
ROYAL ANTHROPOLOGICAL INSTITUTE
OF GREAT BRITAIN AND IRELAND
VOLUME 31. PART 1. 1901.

THE GROWTH OF

ia-salts Year after

Plots.	1844.	1845.	1846.	1853.	1854.
ED CORN per Acre, in					
3	15 0	23 0 $\frac{3}{4}$	17 3 $\frac{3}{4}$	16 5 3 $\frac{1}{4}$	21 0 $\frac{1}{4}$
10a	15 1 $\frac{3}{4}$	31 3 $\frac{1}{4}$	27 1 $\frac{1}{2}$	25 9 3 $\frac{1}{4}$	34 1 $\frac{1}{2}$
10b		31 3 $\frac{1}{4}$	17 2 $\frac{1}{2}$	25 15 2	39 0 $\frac{3}{4}$

lts, and Mixed Minerals

Plots.	1852.	1853.	1854 ³⁵⁵ .	1861.	1862.
DRESSED CORN per Acre, in					
3	13 3 $\frac{1}{4}$	5 3 $\frac{1}{4}$	21 0	3 $\frac{1}{2}$	11 1 $\frac{1}{4}$
5	16 3 $\frac{1}{2}$	10 0 $\frac{1}{2}$	2 1 $\frac{1}{4}$	3 $\frac{1}{2}$	15 1 $\frac{1}{2}$
17	24 3 $\frac{1}{4}$	8 2 $\frac{3}{4}$	0 $\frac{1}{4}$	1	18 2 $\frac{3}{4}$
18	14 1 $\frac{1}{4}$	19 1 $\frac{1}{4}$	0 $\frac{3}{4}$	3 $\frac{1}{4}$	32 3 $\frac{1}{2}$
10a	21 3 $\frac{1}{2}$	9 3 $\frac{1}{4}$	3 $\frac{3}{4}$	5 0 $\frac{1}{2}$	12 3 $\frac{1}{2}$
10b	22 0 $\frac{1}{4}$	15 2	0 $\frac{1}{4}$	28 2 $\frac{1}{2}$	15 3 $\frac{1}{4}$
7	26 3	23 2	0	32 2 $\frac{1}{2}$	34 3 $\frac{3}{4}$

After the 2nd year (1845), 10a and 10b were both manured with ammonia-salts at the rate of 336 lbs. per acre, and gave rather more than $31\frac{1}{2}$ bushels of dressed corn, and rather more than 24 cwt. of straw, against scarcely $23\frac{1}{2}$ bushels of dressed corn, and only $24\frac{1}{2}$ cwt. of straw, on plot 3 without manure. Thus, at a mixed mineral manure gave scarcely any increase whatever in the first year, ammonia-salts alone gave an increase of more than $8\frac{1}{2}$ bushels of dressed corn, and about $13\frac{1}{2}$ cwt. of straw, in the second.

In the 3rd season (1845-6), 10a being again manured with ammonia-salts, gave nearly $27\frac{1}{2}$ bushels of dressed corn, and 20 cwt. of straw, against not quite 18 bushels of dressed corn, and 16 cwt. of straw, on the continuously unmanured plot (3). Ammonia-salts, again used alone, gave, therefore, an increase of nearly $9\frac{1}{2}$ bushels of dressed corn, and about $6\frac{1}{2}$ cwt. of straw. Plot 10b was left this year unmanured, and it gave about 18 bushels less dressed corn, and $\frac{1}{2}$ cwt. less straw, than plot 3. It was, then, neither the unexhausted residue of the mineral manure supplied in 1844, nor that of the ammonia-salts supplied in 1845, gave any increase in 1846.

In the 4th year (1846-7), plots 10a and 10b, so differently treated in the preceding year, were again equally manured with ammonia-salts alone. The result was, almost identical amounts of corn and straw in the two cases, and an increase over the unmanured plot of nearly 9 bushels of dressed corn, and about 10 cwt. of straw.

In the 5th year (1847-8), the two plots again received equal amounts of ammonia-salts, but 10b had in addition a mineral manure supplying potash, soda, magnesia, lime, sulphuric acid, and phosphoric acid. Plot 10b was, therefore, in a more favourable condition than plot 10a, not only by virtue of this direct supply of mineral constituents, but also on account of the less exhaustion of them in 1846, when, being left unmanured, it gave much less both of corn and straw than plot 10a. The result was, that, with $14\frac{3}{4}$ bushels of dressed corn on the unmanured plot (3), 10a, with ammonia-salts alone for the 4th time, gave $23\frac{1}{2}$, and 10b, with ammonia-salts for the 3rd time, and with mineral manure in addition, rather over 25 bushels; and the amounts of straw were, on plot 3, $15\frac{1}{2}$, on plot 10a rather more than 21, and on plot 10b rather more than 26 cwt. There was, therefore, an increase of $4\frac{1}{2}$ bushels of dressed corn, and $5\frac{3}{4}$ cwt. of straw, on plot 10a; and of $10\frac{1}{2}$ bushels of dressed corn, and $10\frac{1}{2}$ cwt. of straw, on plot 10b; or a difference in favour of 10b, due to the greater abundance of mineral constituents, of nearly 16 bushels of dressed corn, and of 5 cwt. of straw. There was, then, already in the 4th year of the application of the ammonia-

salts alone, evidence of considerable relative deficiency of available mineral constituents, notwithstanding the application in the 1st year of silicate of potass and superphosphate of lime. Nor is this to be wondered at when it is considered that, in the 4 crops grown by ammonia-salts alone, there would probably be more than five times as much potass, about three times as much phosphoric acid, and more than thirty times as much silica removed from the land, as would be lost to it in a whole course of rotation of turnips, barley, clover, and wheat—supposing only the corn and meat to be sold, and the manure produced from the straw, and the consumption of the roots and clover, to be returned to the land.

In the 6th year (1848-9) both plots were again equally manured with ammonia-salts alone, and they gave almost identical quantities of dressed corn, amounting to about $13\frac{1}{2}$ bushels more than that on the unmanured plot; whilst, of straw, 10a gave an increase of about 11 cwts., and the much less exhausted plot 10b only about 1 cwt. more.

In the 7th year (1849-50), 10a again received ammonia-salts alone, and gave nearly 27 bushels of dressed corn and $27\frac{1}{2}$ cwts. of straw, which was equal to an increase over the unmanured produce of nearly 11 bushels of corn and about $12\frac{1}{2}$ cwts. of straw. 10b, on the other hand, had a manure supplying liberally every mineral constituent at all likely to be wanting, except silica, but containing no ammonia, and the result was, an increase over the unmanured plot of little over 2 instead of 11 bushels of dressed corn, and of only about 2 instead of $12\frac{1}{2}$ cwts. of straw. Thus, even in the 6th year of their application, ammonia-salts alone gave 9 bushels more dressed corn and nearly $10\frac{1}{2}$ cwts. more straw, than the mixed mineral manure alone, notwithstanding that a relative deficiency of mineral constituents had shown itself 2 years previously, and that even on 10b, where so much less ammonia-salts had been applied in previous years, there had still been considerably more than twice as much nitrogen supplied as had been recovered as increased yield in the crop. The defective result on 10b, by the mineral manure alone, could not be due to the want of available silica, since the exhaustion of it was very much less than on 10a, which, nevertheless, gave so much more produce. It is, moreover, clear that, although the available supply of mineral constituents had become defective in relation to the amount of ammonia artificially supplied, it was still in excess relatively to the annually available supply of nitrogen from natural sources.

From this time forward, for 13 consecutive years, plots 10a and 10b received exactly the same amount of ammonia-salts annually (200 lbs. sulphate and 200 lbs. muriate), and neither of

them any mineral manure. During the first 2 years, the two plots, previously so differently manured, gave almost identical amounts of produce; but from that time forward, 10*b*, which, in the earlier years, had the ammonia-salts omitted twice, and twice received the mixed mineral manure when 10*a* had none, gave every year several bushels of corn (with its proportion of straw) more than 10*a*.

It is clear that 10*a* had become relatively very deficient in certain mineral constituents. Nor is this to be wondered at when the circumstances of the experiment are considered. To say nothing of silica and other constituents, the first 7 crops taken from 10*a* removed about $1\frac{1}{2}$ time as much phosphoric acid, and more than twice as much potass, as were supplied in the first year (1843-4). On the other hand, 10*b* received in manure during the same 7 years, more than $1\frac{1}{2}$ time as much phosphoric acid, and more than twice as much potass, as were removed in the crops. In other words, 10*a* was already much poorer, and 10*b* much richer, in both phosphoric acid and potass, than at the commencement.

If these circumstances are borne in mind the Summary Table XXIX., given overleaf, will have considerable interest.

During the 6 years, 1845-1850, plot 10*a* received 424 lbs. more sulphate and 200 lbs. more muriate of ammonia than plot 10*b*; but during the same period plot 10*b* received 600 lbs. pearl-ash, 400 lbs. soda-ash, 200 lbs. sulphate of magnesia, 400 lbs. bone-ash, and 300 lbs. sulphuric acid (sp. gr. 1.7), whilst plot 10*a* received no mineral manure. The result was, that whilst both plots gave a considerable increase, 10*a* gave a total of $13\frac{1}{2}$ bushels of dressed corn, and 1278 lbs., or about $11\frac{1}{2}$ cwts., of straw, more than 10*b*—equal to an average annual increase of $2\frac{1}{4}$ bushels of dressed corn and nearly 2 cwts. of straw, due to the larger amount of ammonia-salts, notwithstanding the much more favourable condition of 10*b* as to mineral constituents.

Over the next 13 years, 1851-1863, during which neither plot received mineral manure, and both the same amount of ammonia-salts annually, 10*a*, previously so much more exhausted of mineral constituents, gave $51\frac{1}{2}$ bushels of dressed corn, and 5483 lbs., or about 49 cwts., of straw less than 10*b*—equal to an average annual deficiency of nearly 4 bushels of dressed corn, and of $3\frac{1}{4}$ cwts. of straw. It is worthy of remark, however, that although 10*b* continues to give notably more produce than 10*a*, due to the supply, and to the less exhaustion, of mineral constituents during the earlier years, it appears to be of late progressively declining in annual yield, and even somewhat more rapidly than 10*a*; for, if the average annual produce of the last 6 years be compared with

TABLE XXIX.—PRODUCE OF WHEAT ON PLOT 10a compared with that on 10b, during the 6 Years, 1845—1850, the 13 Years, 1851—1863, and the whole 19 Years, 1845—1863.

Plot 10a. Ammonia-salts every Year.

Plot 10b. Without Manure the 2nd Year, with Mineral Manure the 4th and 6th Years, and Ammonia-salts the 1st, 3rd, 4th, 5th, 7th, and succeeding Years.

Plots.	6 Years, 1845—1850.		13 Years, 1851—1863.		19 Years, 1845—1863.	
	Total.	Average Annual.	Total.	Average Annual.	Total.	Average Annual.
Dressed Corn, per Acre; in Bushels and Pecks.						
10a	163 2½	27 1½	300 1½	23 0½	464 0	24 1½
10b	150 1½	25 0½	351 3½	27 0½	502 1½	26 1½
10a over or under 10b	+13 1	+2 1	-51 2½	-4 0	-38 1½	-2 0
Weight per Bushel of Dressed Corn; lbs.						
10a	..	60·3	..	56·3	..	57·6
10b	..	60·6	..	57·4	..	58·4
10a over or under 10b	..	-0·3	..	-1·1	..	-0·8
Total Corn, per Acre; lbs.						
10a	10,728	1788	19,194	1476	29,922	1575
10b	9,833	1639	22,254	1712	32,087	1689
10a over or under 10b	+895	+149	-3,060	-236	-2165	-114
Total Straw (and Chaff), per Acre; lbs.						
10a	17,708	2951	34,302	2639	52,010	2737
10b	16,480	2738	39,785	3060	56,215	2958
10a over or under 10b	+1,278	+213	-5,483	-421	-4,205	-221
Total Produce (Corn and Straw), per Acre; lbs.						
10a	28,436	4739	53,496	4115	81,932	4312
10b	26,263	4377	62,039	4772	88,302	4647
10a over or under 10b	+2,173	+362	-8,543	-657	-6,370	-335

with that of the preceding 6, it is found that, whilst 10*a* has given 1½ bushel of dressed corn and 180 lbs. of straw, 10*b* has given 1½ bushel of dressed corn and 304 lbs. of straw, less over the later than over the earlier period.

Over the whole 19 years, plot 10*a*, with its larger amount of ammonia-salts and less supply of mineral constituents, gave 38½ bushels of dressed corn, and 4205 lbs., or about 37½ cwt., of straw less than 10*b*—equal to an average annual deficiency of 2 bushels of dressed corn, and nearly 2 cwt. of straw.

Here, then, is an obvious case of exhaustion of available mineral constituents relatively to the available supply of nitrogen, and also a very marked effect from the unexhausted residue of the mineral manures applied in the earlier years.

It would be inappropriate to go into detail as to the comparative exhaustion of the two plots in respect to individual mineral constituents without adducing the results of analysis relating to the subject. But it may be stated generally, that the average percentage of mineral matter is considerably lower in the produce of plot 10*a*, than in that of plot 3 without manure; and further, that in the ash of the grain the proportion of phosphoric acid, and in that of the straw the proportion of the silica more particularly, is becoming reduced. During these 19 years, however, there have been removed from the plot as much phosphoric acid as would suffice for more than 50 years, as much potass as would suffice for more than 100 years, and as much silica as would suffice for more than 500 years of ordinary rotation, where only corn and meat are sold, and the due proportion of the home-manures are periodically returned to the land; whilst the first five crops of the twenty would remove about as much phosphoric acid, and the first three about as much potass, as was supplied in the first year of the experiments.* Under such very unusual treatment, it is certainly not surprising that the annually available mineral constituents of the soil should prove to be insufficient.

Diagram II. (facing p. 69), further illustrates the point in question. There are there shown, side by side, the bushels of dressed corn per acre, in each of the last 12 years of the experiments, on plots 3, 5, 17, 18, 10*a*, 10*b*, and 7; and the further

* Baron Liebig tells his readers that we applied in the first year as much soluble phosphoric acid as would be contained in about 1750 lbs. of guano. The fact is, that the total phosphoric acid applied would be contained in about one-half that amount of Peruvian guano of average composition. He also misrepresents our conclusions; and so, as in other instances, by the aid of his own mis-statements, makes a point for ridicule where he cannot controvert. (Einleitung; and 'Natural Laws of Husbandry,' p. 300, and context.)

conditions and results of the different experiments will be sufficiently understood from the following few comments.

It is seen, as shown in another form in Table XXVI., that plots 5, and 17 or 18, give almost identical amounts of average annual produce, and therefore of average annual increase over plot 3, during the 12 years in question—the one (plot 5) having mixed mineral manure alone every year, but succeeding heavy dressings of mineral manure and ammonia-salts in preceding years, and the others having the same mixed mineral manure each year succeeding an excess of ammonia-salts in the preceding year, and succeeding also, as on plot 5, mixed mineral manure and ammonia-salts in the earlier years.

But the point which it is the chief object of Diagram II. to illustrate is, the very different effect of a given amount of ammonia-salts according to the supply of available mineral constituents within the soil.

During each of the 12 years, plots 10*a*, 10*b*, 17 or 18, and 7, each received exactly the same amount of ammonia-salts; and, taking the results of each year separately, the order as to amount of produce is, invariably—plot 7 (highest), 17 or 18, 10*b*, and 10*a* (lowest); that is, the lowest where the mineral constituents were the most exhausted, and the highest where their supply was most liberal.

The point is also well illustrated by reference to the average annual results over the 12 years. Thus, the average annual increase (over the unmanured produce) was:—on 10*a*, with ammonia-salts alone (not only each year of the 12, but for seven years previously), $7\frac{1}{4}$ bushels of dressed corn, and nearly $8\frac{1}{2}$ cwts. of straw; on 10*b*, also with ammonia-salts alone every year of the 12, and for some years previously, but with mineral manure in two of the seven preceding years, nearly $11\frac{1}{2}$ bushels of dressed corn, and $12\frac{1}{2}$ cwts. of straw; on 17 or 18, where ammonia-salts each year succeeded mineral manure, $17\frac{1}{4}$ bushels of dressed corn, and nearly $18\frac{3}{4}$ cwts. of straw; and, lastly, on plot 7, with the ammonia-salts and mixed mineral manure used each year together, nearly 21 bushels of dressed corn, and $22\frac{3}{4}$ cwts. of straw.

With the same amounts of ammonia-salts, therefore, there was a difference in the amount of increase of produce annually obtained of from $7\frac{1}{4}$ bushels of dressed corn and nearly $8\frac{1}{2}$ cwts. of straw, to $20\frac{1}{4}$ bushels of corn and $22\frac{3}{4}$ cwts. of straw, according to the supply of available mineral constituents within the soil. There was a difference of from $7\frac{1}{4}$ bushels of corn and nearly $8\frac{1}{2}$ cwts. of straw, to nearly $11\frac{1}{2}$ bushels of corn and $12\frac{1}{2}$ cwts. of straw, due to the application of mineral manure twice in the earlier years of the experiments (10*b*); and there was a difference

of from 17½ bushels of dressed corn and nearly 18½ cwt. of straw, to 20½ bushels of corn and 22½ cwt. of straw, due to the application of the mixed mineral manure each year in conjunction with the ammonia-salts, instead of each year preceding them as on plots 17 or 18.

In the greater amount of increase on 10*b* than on 10*a*, there is striking evidence of the permanent and lasting effect of the unexhausted residue of the artificially applied mineral constituents, if only available nitrogen be provided within the soil. On the other hand, the greater amount of increase on plot 7 than on plots 17 or 18, shows the much greater effect of the mineral constituents when applied at the same time with the ammonia-salts. Nevertheless, there is no doubt that even plots 17 and 18 received much more of all those mineral constituents that were supplied than was removed of them in the crops. The condition and distribution of the constituents within the soil, would, however, be very different in the two cases.

The very interesting and important results which have been briefly passed in review in this Section, especially those to which the coloured Diagrams refer, may be still more briefly summarised as follows:—

1. A somewhat heavy loam, of fair average wheat-producing quality, taken at the end of a five-course rotation since manuring, gave scarcely any increased produce of wheat in the year of the application when manured with a mixture of silicate of potass and superphosphate of lime; but it gave a very considerable, though progressively diminishing, amount of increase, when afterwards manured for 19 consecutive years with ammonia-salts alone.

2. It is obvious that, taken in the condition of practical exhaustion specified, the soil still contained an excess of annually available mineral constituents, relatively to the annually available nitrogen supplied by soil and season without manure. When, however, large quantities of ammonia-salts were annually applied, the relative deficiency of mineral constituents became apparent, even as early as the fourth year of their application.

3. When ammonia-salts were applied, the greater portion of the nitrogen remained unrecovered as increased yield in the crop for which it was employed.

4. The unexhausted residue of nitrogen supplied as manure, was but very partially and very slowly recovered as increased yield in succeeding years, even when followed by the liberal application of such mineral manure as was very effective when used in conjunction with newly applied ammonia-salts.

5. Mineral constituents supplied in the soluble form in the 5th and 7th years of the experiments (though giving very little

increase when in the latter year they were used alone), continued to increase the effect of ammonia-salts afterwards annually applied for 13 consecutive years.

6. A given amount of ammonia-salts gave very different amounts of increase, according to the supply of available mineral constituents within the soil; giving very much more when mineral manures were applied in the same, than in the preceding year, notwithstanding that, in the latter case, there could be no deficiency, though doubtless less favourable condition and distribution of the mineral constituents.

7. The same mineral manures which were very effective when supplied with ammonia-salts, gave very little increase of produce when used alone year after year for 12 years, although following an excess of ammonia-salts applied in preceding years; and they gave very little more when they were applied every year succeeding an excess of ammonia-salts applied in the immediately preceding year.

8. The unexhausted residue from previous mineral manuring, though it served as an effective reserve against exhaustion, had little or no effect in increasing the growth of wheat without the aid of available nitrogen provided within the soil. An unexhausted residue from previous nitrogenous manuring had also but little influence upon the immediately succeeding crops, even when aided by the application of mineral manures.

The bearing of the facts adduced in this Section, upon the question of the probable influence on the mineral wealth of our soils, of the use of artificial nitrogenous manures, under the circumstances, and in the degree, in which they are generally employed in the ordinary course of agriculture in this country, will be considered further on, when the whole of the experimental evidence which it is proposed to bring forward in the present Report is before the reader.

With regard to the bearing of the results on the subject of the next Section, it is obvious that the degree and limit of effect of the unexhausted residue of previous manuring, whether nitrogenous or mineral, are such that, if the circumstances of the different plots are duly considered, there will be little danger of misinterpreting the results obtained on the application of the different manures year after year on the same plot during the last 12 years.

III. AVERAGE ANNUAL RESULTS OVER THE LAST 12 YEARS.

Subject to such reservations as the facts already adduced suggest, and to others which will be referred to in the course of the discussion, attention may now be directed to the average annual

results over the last 12 years, from each description of manure applied year after year on the same plot, during the whole of that period. These are given in Table XXX., pp. 78, and 79. The details of the manures are given in Appendix Table IX., and are further explained in the Notes at p. xix, facing that Table. The details of the produce of each separate plot in each separate year will be found in Appendix Tables X.—XXVI., pp. xx-xli.

It may be explained that in the Summary Table XXX., wherever the plots are divided into two (*a* and *b*), and both portions are manured alike, giving duplicate experiments and results, the mean of the two only is given.

Average Annual Produce without Manure. †

There were three plots entirely unmanured during the last 12 years of the experiments to which the results in Table XXX. refer. Plot 3, had been unmanured for the 8 preceding years also, as well as during the 5 years of rotation before the experiments commenced. Plot 20, which was at the other side of the field, had been unmanured the same number of years as plot 3, with the exception that in the third year it received a mixture of the surplus of the artificial manures used on the other plots. Plot 4 had been unmanured during the last 12 years only; during the preceding 7 years it had been manured with large quantities of superphosphate of lime and sulphate of ammonia, and in the first year of the 20 was manured with the ashes of farmyard manure.

Plot 3, which had grown wheat without manure for the whole 20 years, and plot 20 for 19 out of the 20, gave almost identical average annual amounts of produce over the last 12 years. On almost every point, however, plot 20 gave slightly the better result; but the difference is so small that the experiments mutually confirm each other, and the produce of plot 3 (continuously unmanured) is adopted as the standard by which to compare that of the manured plots.

Its average annual yield per acre over the 12 years was 15½ bushels of dressed corn, and 1662 lbs. or nearly 15 cwts. of straw. The average weight per bushel of the dressed corn was lower than in any case but two of the manured produce; but the proportion of corn to straw was almost exactly the same as with farmyard manure, and higher than in most cases with artificial manure.

The tendency to produce a fair proportion of corn to straw was, therefore, without manure, more than equal to that under the majority of the conditions with manure; and the low weight per bushel was, doubtless, due to the sluggish growth and consequent defective power of ripening.

Plot 4,

Report of Experiments on the Growth of Wheat.

EXPERIMENTS AT ROTHAMSTED ON THE GROWTH OF
TABLE XXX.—AVERAGE PRODUCE, and INCREASE by MANURE,

Plots.	Manures per Acre, per Annum, for 12 Years; 1852-1863. (For further particulars see Appendix Table IX. and Notes, pp. xviii-xix; and for the Manures previous to 1852 see Appendix Tables I.-VIII. pp. ii-xvii.)	PRODUCE, &c.			
		Dressed Corn.		Total Corn.	
		Quantity.	Weight per Bushel.		
2	14 Tons Farmyard Manure, every year (20 years, 1844-63)	bush. pks. 35 1½	lbs. 59·3	lbs. 2232	
3	Unmanured (20 years, 1844-63)	15 2	56·5	964	
20	Unmanured (17 years, 1847-63)	15 2½	57·0	989	
4	Unmanured (12 years, previously Superphosphate of Lime and Ammonia-salts)	16 3½	57·2	1072	
0	Superphosphate of Lime ¹ (16 years, 1848-63)	18 1	57·5	1143	
1	Sulphates of Potass, Soda, and Magnesia (15 years, 1849-63)	16 1½	57·2	1025	
5 (a & b)	Mixed Mineral Manure ²	18 1½	57·9	1157	
21	100 lbs. Muriate Ammonia, and Mixed Mineral Manure ..	22 0½	57·9	1384	
22	100 lbs. Sulphate Ammonia, and Mixed Mineral Manure ..	21 2½	57·8	1362	
6 (a & b)	200 lbs. Ammonia-salts ³ , and Mixed Mineral Manure ..	28 1½	58·6	1771	
7 (a & b)	400 lbs. Ammonia-salts, and Mixed Mineral Manure ..	36 1½	58·4	2275	
8 (a & b)	600 lbs. Ammonia-salts, and Mixed Mineral Manure ..	38 0	57·8	2382	
16 (a & b)	800 lbs. Ammonia-salts, and Mixed Mineral Manure ..	38 2	57·6	2425	
17 (a & b) or 18 (a & b)	Mixed Mineral Manure (in alternation with 400 lbs. Ammo- nia-salts) 400 lbs. Ammonia-salts (in alternation with Mixed Mineral Manure)	18 3½ 32 2½	58·0 58·7	1187 2054	
10 (a)	400 lbs. Ammonia-salts, alone (19 years Ammonia-salts alone, 1845-63)	22 2½	55·9	1435	
10 (b)	400 lbs. Ammonia-salts, alone (13 years, 1851-63)	26 3½	57·0	1693	
11 (a & b)	400 lbs. Ammonia-salts, and Superphosphate of Lime ..	29 2½	56·5	1859	
12 (a & b)	400 lbs. Ammonia-salts, Superphosphate of Lime, and Sul- phate of Soda	35 0½	58·3	2200	
13 (a & b)	400 lbs. Ammonia-salts, Superphosphate of Lime, and Sul- phate of Potass	34 2½	58·6	2184	
14 (a & b)	400 lbs. Ammonia-salts, Superphosphate of Lime, and Sul- phate of Magnesia	35 0	58·3	2193	
9 (a)	550 lbs. Nitrate of Soda, and Mixed Mineral Manure ⁴ ..	34 2	57·1	2161	
9 (b)	550 lbs. Nitrate of Soda, alone ⁵	25 3½	55·4	1621	
15 (a)	400 lbs. Ammonia-salts, Mixed Alkalies ⁶ , and Superphos- phate of Lime ⁷	33 0½	58·6	2088	
15 (b)	300 lbs. Ammonia-salts, Mixed Alkalies, ⁶ Superphosphate of Lime, ⁷ and 500 lbs. Rape-Cake	34 3½	58·7	2186	
19	300 lbs. Ammonia-salts, Superphosphate of Lime, ⁷ and 500 lbs. Rape-cake	31 2½	58·1	2016	

¹ "Superphosphate of Lime"—4 parts Bone-ash, and 3 parts Sulphuric Acid, Sp. gr. 1·7.² "Mixed Mineral Manure"—Superphosphate of Lime, and Sulphates of Potass, Soda, and Magnesia.³ "Ammonia-salts"—equal parts Sulphate and Muriate of Ammonia of Commerce.⁴ 9a—the Mixed Mineral Manure not applied until the 12th Season, 1854-5; and only 475 lbs. Nitrate

WHEAT YEAR AFTER YEAR ON THE SAME LAND.

per Acre, per Annum, over 12 Years, 1852-63.

PRODUCE, &c.			INCREASE.								Plots.
Straw (and Chaff).	Total Produce (Corn and Straw).	Corn to 100 Straw.	Dressed Corn.		Total Corn.		Straw and Chaff.		Total Produce.		
			Over Un- manured (Plot 3).	Over Mixed Mineral Manure (Plots 5a & b).	Over Un- manured (Plot 3).	Over Mixed Mineral Manure (Plots 5a & b).	Over Un- manured (Plot 3).	Over Mixed Mineral Manure (Plots 5a & b).	Over Un- manured (Plot 3).	Over Mixed Mineral Manure (Plots 5a & b).	
lbs.	lbs.		bush. pks.	bush. pks.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
3869	6101	57.9	19 3½	..	1268	..	2207	..	3475	..	2
1662	2626	57.8	..	..	..	..	..	..	..	..	3
1714	2703	57.9	0 0½	..	25	..	52	..	77	..	20
1732	2804	61.6	1 1½	..	108	..	70	..	178	..	4
1846	2989	61.9	2 3	..	179	..	184	..	363	..	0
1767	2792	58.0	0 3½	..	61	..	105	..	166	..	1
1897	3054	62.0	2 3½	..	193	..	235	..	428	..	5 (a & b)
2343	3727	59.7	6 2½	3 3	420	227	681	446	1101	673	21
2308	3670	59.0	6 0½	3 1	398	205	646	411	1044	616	22
3012	4783	59.0	12 3½	9 3½	807	614	1350	1115	2157	1729	6 (a & b)
4212	6487	54.1	20 3½	17 3½	1311	1118	2550	2315	3861	3433	7 (a & b)
4715	7097	50.4	22 2	19 2½	1418	1225	3053	2818	4471	4043	8 (a & b)
5152	7577	47.3	23 0	20 0½	1461	1268	3490	3255	4951	4523	16 (a & b)
1992	3179	59.7	3 1½	0 1½	223	30	330	95	553	125	17 (a & b) or 18 (a & b)
3755	5809	55.0	17 0½	14 0½	1090	897	2093	1858	3183	2755	
2603	4038	54.0	7 0½	4 0½	471	278	941	706	1412	984	10 (a)
3061	4754	54.6	11 1½	8 2	729	536	1399	1164	2128	1700	10 (b)
3233	5092	57.1	14 0½	11 0½	895	702	1571	1336	2466	2038	11 (a & b)
3947	6147	56.7	19 2½	16 3	1236	1043	2285	2050	3521	3093	12 (a & b)
3980	6173	54.9	19 0½	16 0½	1220	1027	2327	2092	3547	3119	13 (a & b)
4001	6199	54.9	19 2	16 2½	1234	1041	2339	2104	3573	3145	14 (a & b)
4426	6587	48.5	19 0	16 0½	1197	1004	2764	2529	3961	3533	9 (a)
3187	4808	49.8	10 1½	7 1½	657	464	1525	1290	2182	1754	9 (b)
3795	5883	54.9	17 2½	14 3	1124	931	2133	1898	3257	2829	15 (a)
4028	6214	54.4	19 1½	16 1½	1222	1029	2866	2131	3588	3160	15 (b)
3521	5537	57.2	16 0½	13 1	1052	859	1859	1624	2911	2483	19

of Soda for the 9th, and 275 lbs. for the 10th, and 11th Seasons.

^a 96—in the 9th Season only 475 lbs. of Nitrate of Soda.

^b “Mixed Alkalies”—Sulphates of Potass, Soda, and Magnesia.

^c For Plots 15a, 15b, and 19, the Bone-ash decomposed by Muriatic Acid of Commerce, instead of Sulphuric Acid.

Plot 4, unmanured for the 12 years only, and manured for 7 years previously with superphosphate of lime and ammonia-salts, and for 1 year with the ashes of farmyard dung (supplying very much more phosphoric acid than was removed in the crops, and considerably more of nitrogen and of every mineral constituent than was removed in the increase of the crops), gave an annual average during the subsequent 12 years of nearly $1\frac{1}{2}$ bushel of dressed corn, and a little straw also, more than either plot 3 or plot 20. Bearing this difference in mind, we shall see that the result accords very well with that of the other unmanured plots; and, as shown more in detail in Section II., usefully indicates the limit of effect on immediately succeeding crops of an unexhausted residue from previous manuring. It is worthy of remark, however, that the produce of this plot had nearly as high a proportion of corn to straw as that of any in the entire series; being only surpassed on this point by that of plots 0 and 5, on which, as on plot 4, phosphoric acid would be present in large proportion relatively to other constituents, when compared with the condition of other plots in this respect.

An average annual produce of wheat, amounting to from 15 to 16 bushels of corn, and from 15 to 16 cwts. of straw, without manure of any kind, is looked upon by many as an extraordinary yield, and as indicating a somewhat unusual quality of land. There is no doubt that it bears a higher proportion than might be expected, to the produce obtained, even under rotation with periodical manuring, in a large majority of cases where land is badly farmed, and deficient range and aeration of soil, luxuriant weeds, and defective manuring, have all their share in the miserable result. The experimental land, though kept extremely clean, was not, however, ploughed more deeply than in the ordinary practice of the farm; and, there can be little doubt, that a large proportion of those soils of the country which are recognised as possessing average wheat-producing qualities, would yield very similar results, if kept equally clean and otherwise as well cultivated; whilst some would, under like conditions, produce much more, though, many light soils probably much less.

Average Annual Produce by Farmyard Manure.

The average annual produce by farmyard manure over the last 12 years was $35\frac{3}{8}$ bushels of dressed corn, and 3869 lbs. or about $34\frac{1}{2}$ cwts. of straw; equal to an average annual increase over the produce of plot 3 of nearly 20 bushels of corn, and nearly 20 cwts. or 1 ton of straw.

As has been already pointed out (see Table XXII. and comments thereon), whilst the average annual produce without manure was nearly the same during the earlier and the later

years, that by farmyard manure was very much greater over the last 10 than the first 10 years of the experiments; though it increased in a considerably less degree during the last 6 as compared with the preceding 6 years.

The total produce during the 20 years was, without manure, $324\frac{1}{2}$, and with farmyard manure $648\frac{1}{2}$ bushels of dressed corn; and without manure $302\frac{1}{2}$, and with farmyard manure $627\frac{1}{2}$ cwts. of straw; or almost exactly double the amount of corn, and more than double the amount of straw, with the farmyard manure. It further gave nearly double as much average annual increase of corn, and more than $1\frac{1}{2}$ times as much increase of straw, over the second as over the first 10 years; and whilst the weight per bushel of the dressed corn was, without manure lower during the later than during the earlier half of the period, with the farmyard manure it was higher during the later period.

During the whole 20 years 280 tons of farmyard manure were applied per acre, and there have been yielded about $18\frac{1}{2}$ tons of corn and nearly $31\frac{1}{2}$ tons of straw, equal to nearly 50 tons of total produce. The manure applied would not only convey to the land more of every constituent than was contained in the increase of crop, but nearly twice as much dry organic matter, and much more than twice as much of nitrogen, phosphoric acid, and potass (and probably every other mineral constituent), as was contained in the total produce removed from the land. There has, therefore, been a great accumulation of constituents by the soil. No wonder, then, that the plot should yield such a much higher average annual produce during the later than during the earlier years. On the other hand, several of the artificial manures gave a considerably higher average produce than the farmyard manure; and whilst several gave more than 50 bushels in the twentieth season, 1863, without any artificial supply of either available silica or carbonaceous organic matter during the whole period of the experiments, the farmyard manure gave only 44 bushels, and also less straw. It gave, however, the highest weight per bushel in the series.

A consideration of the results obtained by the other manures will indicate to which of the constituents of the farmyard manure its effects were mainly due, and which were superfluous, if not even in some way instrumental in limiting the productive activity of the constituents associated with them.

Average Annual Produce by Mineral Manure alone.

Plots 0, 1, and 5 had each mineral manure alone during the last 12 years.

Plot 0 was manured with a large quantity of superphosphate

of lime alone in each of the 12, and in the 4 preceding years, and previously with Peruvian guano or the mixture of the surplus of the other manures. Under these conditions the average annual produce during the last 12 years was $18\frac{1}{2}$ bushels of dressed corn, and 1846 lbs., equal about $16\frac{1}{2}$ cwts. of straw; equivalent to an average annual increase over the unmanured plot of only $2\frac{1}{2}$ bushels of corn, and 184 lbs. of straw, and to a deficiency compared with the produce by farmyard manure of about 17 bushels of corn, and 18 cwts. of straw. Since a portion of the small increase was, doubtless, due to the unexhausted residue of previous nitrogenous manuring, it is obvious that but little remains to be attributed to the subsequent annual supply of superphosphate of lime. It is obvious, too, that if it were in mineral constituents that the soil had become relatively deficient by the previous cropping, it was not for want of phosphoric acid alone that the plot yielded so little more produce than was obtained without manure, and so much less than was obtained with farmyard manure.

Nor was it in potass, soda, magnesia, and sulphuric acid alone, that the soil had become relatively exhausted; for on plot 1 these constituents were supplied liberally every year for 15 consecutive years, and the average annual produce and increase over the 12 years were even less than on plot 0 with superphosphate of lime. The increase over the unmanured produce was, in fact, not quite 1 bushel of dressed corn, and not quite 1 cwt. of straw, per acre per annum.

Plot 5, was manured with a mixture of both superphosphate of lime, and the sulphates of potass, soda, and magnesia, supplying to the soil much more of probably every mineral constituent, except silica, than was taken off in the crops. But this mixture gave scarcely any more increase than the superphosphate of lime alone, and part of that which it did give has been shown to be most probably due to the unexhausted residue of previous nitrogenous manuring.

It was not, therefore, for want of mineral constituents, unless of available silica, that the soil had become, by the previous cropping, incapable of producing full wheat crops. The defective result, as compared with that by farmyard manure, was obviously due to the want of some constituent which was supplied by it, but not in either of the artificial mineral manures. The questions arise—was the wanting constituent available silica?—was it organic matter yielding carbon to the plant?—or was it nitrogen in some available form of combination? These questions will be pretty satisfactorily answered by the results considered in the next Section.

Average Annual Produce by Mineral Manure and Ammonia-Salts.

The plots included in this series are Nos. 21, 22, 6, 7, 8, and 16, to each of which exactly the same mixed mineral manure (consisting of superphosphate of lime and the sulphates of potass, soda, and magnesia) was applied as that which was used alone on plot 5, and then gave less than $18\frac{1}{2}$ bushels produce, and less than 3 bushels' increase of dressed corn; but it was now employed in conjunction with ammonia-salts, in amounts varying from 100 lbs. to 800 lbs. per acre per annum.

On plot 21 the mixed mineral manure was used with 100 lbs. of the muriate, and on plot 22 with 100 lbs. of the sulphate of ammonia of commerce. The muriate contained rather more ammonia than the sulphate, and gave rather more than 22 bushels, whilst the latter gave rather less, and also rather less straw. The increase over the produce by the mixed mineral manure alone, was $3\frac{3}{4}$ bushels of corn and 4 cwts. of straw with the muriate, and $3\frac{1}{4}$ bushels of corn and rather less than $3\frac{3}{4}$ cwts. of straw with the sulphate. In each case, therefore, the addition of 100 lbs. of ammonia-salt to the mixed mineral manure, gave more increase over the produce by the mineral manure alone, than was obtained over the unmanured produce by the use of the mineral manure itself, though it supplied annually an abundance of potass, soda, magnesia, lime, phosphoric acid, and sulphuric acid.

Yet the proportion of increase obtained for a given amount of ammonia in these two experiments was less than is usual when such moderate quantities are used. Indeed, the results which follow will show that it was considerably less than when twice, and even four times as much ammonia was employed with the same mineral manure. The fact is, plots 21 and 22 were comparatively short lengths of land, so near to the hedge-green as to be to some extent affected by trees (especially 21), and they were only brought under exact experiment in the ninth and succeeding years as being the most eligible of the remaining unallotted portions of the experimental field. Their results are, therefore, not so trustworthy as those obtained on the other and larger areas.

On plots 6, 200 lbs. of ammonia-salts (equal parts sulphate and muriate) were used with the mineral manure, and the mixture gave an average annual produce of $28\frac{1}{2}$ bushels of dressed corn, and 3012 lbs. = nearly 27 cwts. of straw, or an increase over the produce by the mixed mineral manure alone of $9\frac{1}{4}$ bushels of corn, and 1115 lbs. = nearly 10 cwts. of straw, which is much more for a given amount of ammonia than was obtained on plots 21 and 22, where the smaller amounts of ammonia-salts were employed.

On plots 7, the amount of ammonia-salts was again doubled, 400 lbs. being now used. The average annual produce amounted to $36\frac{3}{8}$ bushels of dressed corn, and to 4212 lbs. = about $37\frac{1}{2}$ cwt. of straw; and the increase over the produce with the mixed mineral manure alone was very nearly 18 bushels of dressed corn, and 2315 lbs. = about $20\frac{1}{2}$ cwt. of straw.

The proportion of increase for a given amount of ammonia-salts was in corn not quite so great, but in straw rather more, when 400 than when only 200 lbs. of ammonia-salts were used. But 400 lbs. is a very heavy dressing; and although it may, under favourable circumstances, give proportionally as much increase as a smaller amount, it is doubtless more than in the case of the soil in question, or indeed of most soils, is calculated to give on the average of seasons, a maximum result for a given amount of ammonia employed.

Still, even with 600 lbs. of ammonia-salts (plots 8) there was a further increment, and with 800 lbs. (plots 16) still a further increment of increase; though at a much diminishing rate for a given amount of ammonia the greater the quantity employed, and the diminution was the greater in the corn than in the straw.

Thus, by the addition to the mixed mineral manure of 200 lbs. of ammonia-salts there were obtained $9\frac{7}{8}$, by 400 lbs. nearly 18, by 600 lbs. little more than $19\frac{1}{2}$, and by 800 lbs. little more than 20 bushels increase of corn; and of increase of straw there was obtained by 200 lbs. of ammonia-salts 1115 lbs., by 400 lbs. 2315 lbs., by 600 lbs. 2818 lbs., and by 800 lbs. 3255 lbs. Exhibited from a more striking point of view, the result is, that each successive increment of 200 lbs. of ammonia-salts gave increased produce as under:—

	Corn.	Straw.
	Bush. pks.	lbs.
1st increment (200 lbs. applied) gave	9 $3\frac{1}{2}$	1115
2nd increment (400 lbs. applied) „	8 $0\frac{1}{4}$	1200 more than 200 lbs.
3rd increment (600 lbs. applied) „	1 $2\frac{1}{4}$	503 „ 400 lbs.
4th increment (800 lbs. applied) „	0 2	437 „ 600 lbs.

It is seen that any additional produce yielded by the use of more than 400 lbs. of ammonia-salts per acre, was obtained at the cost of very much more ammonia for a given amount of increase. Moreover, as an inspection of Table XXX. will show, the weight per bushel of dressed corn was less, and the proportion of corn to 100 of straw very much less, under the influence of the excessive amounts of ammonia-salts.

Before leaving this series of experiments, attention should be called to the fact, that where 400 lbs., and upwards, of ammonia-salts were used in conjunction with the mixed mineral manure, the produce, both corn and straw, exceeded that by farmyard

manure, with all its supply of silica, and organic matter yielding carbon, both of which were entirely absent in the artificial manures. To this point further reference will be made.

Average Annual Produce by 400 lbs. of Ammonia-Salts per Acre, alone, in alternation with the Mixed Mineral Manure, and in combination with different descriptions of Mineral Manure.

Throughout the preceding series the same mixed mineral manure was always used, but in conjunction with varying amounts of ammonia-salts. In the series now to be considered, a fixed quantity of ammonia-salts (400 lbs. per acre per annum) was employed throughout, but under varying conditions as to the supply of mineral constituents.

The results of this series which stand first in order in the Table, those of plots 17 and 18, where the ammonia-salts were used in alternation with the mixed mineral manure, have been so fully discussed in Section II. (pp. 65 and 74-75) that it is only necessary here to recall attention to the fact, that under these conditions the 400 lbs. of ammonia-salts gave an average annual increase of scarcely $14\frac{1}{2}$ bushels of dressed corn, and only 1858 lbs. = $16\frac{1}{2}$ cwts. of straw, more than the mineral manure alone; whilst the same amount of ammonia-salts, used in conjunction with the mineral manure, as on plots 7, gave an increase of nearly 18 bushels of dressed corn, and 2315 lbs. = $20\frac{3}{4}$ cwts. of straw.

It has also already been shown how much less was the effect of 400 lbs. of ammonia-salts when used for 19 years without mineral manure, as on plot 10a, or for 13 years only, as on plot 10b, than when they were used in conjunction, or even in immediate alternation, with the mixed mineral manure.

The results next in order, those of plots 11, 12, 13, and 14, show in an interesting manner the more or less diminished effect when the mineral manure was less complete than the so-called "mixed mineral manure" employed on plots 17, 18 and 7, and occasionally on plot 10b.

During the first 8 years of the 20, that is, during the 8 immediately preceding the 12 the average produce of which is now under consideration, plots 11, 12, 13, and 14, all received in manure from $2\frac{1}{2}$ to 3 times as much phosphoric acid as was taken off in the crops, and all much about the same excess. Of potass, all four plots yielded much about the same amount in their produce; but whilst plot 11 received no direct supply in manure (only a small quantity in rape cake), plots 12, 13, and 14, each received from two to three times as much as was removed from them; the accumulation being somewhat the greatest on plot 13.

During the last 12 years, in addition to the 400 lbs. of ammonia-salts per acre per annum, plots 11 have had superphosphate

of lime, plots 12 superphosphate of lime and sulphate of soda, plots 13 superphosphate of lime and sulphate of potass, and plots 14 superphosphate of lime and sulphate of magnesia. The object of this arrangement was to trace, by the exclusion of certain constituents, the point at which they, respectively, became deficient.

Up to the present time there is scarcely an appreciable difference in the amounts of produce on plots 12 with soda to the exclusion of potass and magnesia, on plots 13 with potass to the exclusion of soda and magnesia, and on plots 14 with magnesia to the exclusion of potass and soda. It is obvious, therefore, that either the available natural, or the previous artificial, supplies of the respective bases within the soil, have so far prevented relative deficiency of either.

When, however, the produce of these three plots is compared with that of plots 7, manured each year with the same amounts of ammonia-salts and superphosphate of lime, and, in addition, a mixture of the sulphates of potass, soda, and magnesia, instead of only one of them, it is found that they give annually from 1 to 2 bushels less corn, and from 200 to 300 lbs. less straw. It would appear, therefore, that even though there might be neither an actual nor a relative deficiency of either of the bases where only one was supplied, the state of combination, and the distribution within the soil, were the more favourable, and consequently the supply was the more easily available, when all were supplied together.

There is here, again, evidence of the fact already frequently illustrated, that a direct supply of a given amount of manure has frequently more effect upon the immediate crop, than an equal or even much greater quantity accumulated and distributed within the soil in the condition of unexhausted residue from previous manuring.

On plots 11, to which neither potass, soda, nor magnesia has been applied, excepting in small quantity in rapeseed in the earlier years, the average annual produce over the last 12 years was more than 5 bushels of dressed corn, and more than 700 lbs. of straw less than on either plots 12, 13, or 14 with either potass, soda, or magnesia, and it was nearly 7 bushels of corn and nearly 1000 lbs. of straw less than on plot 7, where all three were employed in addition to the manures of plot 11.

It is clear that the point of relative deficiency of one or more of the bases had here been reached; and judging from the composition of the ash of the produce of this plot (11) compared with that of plots 12, 13, and 14, it would appear that it is of available potass that the plot has become the most deficient. The crop has generally appeared pretty healthy and luxuriant

during the earlier stages of growth, but of late years the bulk has perceptibly declined, and the proportion of blighted ears has increased in a remarkable degree. Still, the average proportion of corn to straw is higher than in any case with equal or higher amounts of total produce per acre grown by artificial manures. It will be remembered that it was on plots 0, 4, and 5, where, as on these plots 11, phosphoric acid was relatively very abundant, that the highest proportion of corn to straw in the series was obtained. On the other hand, excepting one or two other marked cases of defective manuring, the weight per bushel of the dressed corn of plots 11 was almost the lowest in the series. There was, therefore, with a full average tendency of growth for the production of a fair proportion of corn, at the same time very defective power of maturation.

It has been seen how very ineffective were mineral manures either to bring into activity the unexhausted residue of previous nitrogenous manuring, or to give increase by inducing a greater accumulation of nitrogen by the plant from natural sources; but the results of the series of experiments now under consideration clearly show, how very effective and lasting were the mineral manures employed, to meet the demands made upon the soil for mineral constituents by the use of the nitrogenous manures even in distant succeeding seasons.

Average Annual Produce by Nitrate of Soda, used alone, or with the Mixed Mineral Manure.

During the last 12 years plot 9b has been manured with nitrate of soda alone, at the rate of 475 lbs. per acre in the first, and of 550 lbs. in each of the 11 succeeding years. The latter amount was taken as equivalent in nitrogen to the 400 lbs. of ammonia-salts applied in so many of the other experiments; but as of late years nitrate of soda of commerce has been purer than formerly, it was probably slightly more than equivalent in nitrogen to the mixture of 200 lbs. of muriate and 200 lbs. of sulphate of ammonia of commerce. During the preceding 8 years 9b was manured with ammonia-salts 7 times, once with rape-cake in addition, in the 1st and 5th seasons received superphosphate of lime, and in the 6th was unmanured. It was, in fact, at the commencement of the 12 years, in a condition intermediate between that of plots 10a and 10b so far as the supply of mineral constituents was concerned; and the effect of the nitrate will be best brought to view by comparing the results with those of these two plots manured with ammonia-salts.

Whilst 400 lbs. of ammonia-salts alone, applied for 19 years on plot 10a, and for 13 years on plot 10b, gave an average

annual produce over the last 12 years, on the former of $22\frac{3}{4}$ bushels of dressed corn, and 2603 lbs. = $23\frac{1}{4}$ cwt. of straw, and on the latter of $26\frac{3}{4}$ bushels of corn, and 3061 lbs. = about $27\frac{1}{4}$ cwt. of straw, a nearly identical, but perhaps rather higher, amount of nitrogen applied as nitrate of soda during the 12 years only on plot 9b, gave $25\frac{3}{4}$ bushels of dressed corn, and 3187 lbs. = nearly $28\frac{1}{4}$ cwt. of straw. The nitrate has, therefore, given rather less corn, but rather more straw than the ammonia-salts on plot 10b; and whilst it is probable that the nitrate supplied rather more nitrogen than the ammonia-salts, the mineral condition of plot 10b was doubtless more favourable than that of plot 9b.

The conditions and the results were, however, sufficiently near in the two cases to indicate that a given amount of nitrogen will probably, in the average of seasons, and under parallel conditions of soil, give very nearly identical results, whether supplied as nitrate of soda or as ammonia-salts. There is, however, little doubt that nitrogen in the condition of the nitrate becomes more rapidly distributed in the soil, and is more rapidly active. Hence its suitability for Spring dressings; and, hence also in a great measure its tendency to favour great luxuriance of stem and leaf, which, under unfavourable conditions of soil and season, leads to the production of an undue proportion of straw.

On plot 9a, in the 1st year of the twelve 475 lbs., and in the 2nd and 3rd, 275 lbs. of nitrate of soda alone were applied; but during the last 9 years the same amount as on plot 9b (550 lbs.) has been applied, and not alone, but in conjunction with the mixed mineral manure. The results with nitrate of soda and mineral manure on plot 9a, compare best with those of ammonia-salts and mineral manure on plot 7; though, taken over the whole 12 years, 9a received neither quite so much nitrogen nor so much mineral manure as plot 7. Comparing the results as they stand, the average annual produce with the ammonia-salts and mineral manure was $36\frac{3}{4}$ bushels of dressed corn, and 4212 lbs. = rather over $37\frac{1}{4}$ cwt. of straw, against $34\frac{1}{4}$ bushels of dressed corn, and 4426 lbs. = $39\frac{1}{4}$ cwt. of straw, with the nitrate and the mineral manure; or nearly 2 bushels less corn, but nearly 2 cwt. more straw, equal about 100 lbs. more total produce, with the nitrate than with the ammonia-salts.

Here again, then, when used in conjunction with a mineral manure supplying liberally every constituent likely to be needed except silica, as well as when used alone, the nitrate indicated a tendency to produce more straw and less corn than the ammonia-salts. Indeed, the crops growing on the nitrated plots always showed to the eye during growth, more stem, and broader leaves, than those grown under otherwise parallel conditions with ammonia-salts.

Average Annual Produce on Plots 15a, 15b, and 19.

Several incidental points were sought to be determined by this series.

During the whole 12 years, and for several years previously, each plot received, respectively, the same manure year after year. All had the same amount of bone-ash as in the so-called mixed mineral manure, but acted upon by hydrochloric instead of sulphuric acid. Plots 15a, and 15b, had also the same amounts of sulphates of potass, soda, and magnesia as in the mixed mineral manure, but plot 19 had none of these. Further, 15a had also annually 400 lbs. of sulphate of ammonia, and plots 15b and 19, 300 lbs. sulphate of ammonia and 500 lbs. rapeseake.

The object of substituting 400 lbs. of sulphate of ammonia, as on plot 15a, by 300 lbs. of sulphate of ammonia and 500 lbs. of rapeseake on 15b and 19, was to supply nearly the same amount of nitrogen in the three cases, with in the two latter a certain amount of organic matter in addition, yielding by decomposition carbon in an available form to the plant. The amount of rapeseake used would, in fact, contain rather more nitrogen than the sulphate of ammonia it substituted; but, owing to the comparatively slow action of the rapeseake, there would probably be not more annually available until after some years of accumulation. The rapeseake would, of course, also supply a certain amount of mineral constituents. Upon the whole, then, it might be expected that, independently of its superiority or otherwise as supplying carbon-yielding matter, the 500 lbs. of rapeseake used year after year would be somewhat more effective than the 100 lbs. sulphate of ammonia which it substituted.

The effects of these several combinations will be best tested by comparing the results with those of plots 7. The only material difference between the manuring of the latter and that of 15a was, that in the manure of 15a the bone-ash was acted upon by hydrochloric acid instead of sulphuric acid, and there was about 8 per cent. or about one-twelfth less ammonia. The result was an average of rather more than 3 bushels of dressed corn, and of 417 lbs. = about $3\frac{1}{2}$ cwts. of straw, less than on plots 7. About one-half of this deficiency may be attributed to the less amount of ammonia supplied, the remainder only being due to the less effective condition of the bone-ash acted upon by hydrochloric instead of sulphuric acid.

Plot 15b, manured exactly as 15a, excepting that 100 lbs. of the sulphate of ammonia was replaced by 500 lbs. of rapeseake, gave more nearly the amount of produce of plots 7, yielding $1\frac{1}{2}$ bushel of dressed corn, and rather more than 2 cwts. of straw, more than 15a, though still $1\frac{1}{2}$ bushel of corn and 184 lbs. of

straw less than plots 7. There is no evidence, therefore, of any marked effect from the carbonaceous organic matter of the rape-cake.

Plot 19 was manured during the 12 years in the same way as 15*b*, with the exception that the sulphates of potass, soda, and magnesia, were omitted. It should be further observed, that whilst during the first 8 years of the 20, plot 15*a* received of potass in manure nearly, and 15*b* over, 400 lbs. more, plot 19 received nearly 200 lbs. less, than was removed in the crops. There was, therefore, a considerable relative deficiency of potass in the soil of plot 19, and it gave an annual average produce of nearly 3½ bushels of dressed corn, and about 4½ cwt. of straw, less than plot 15*b*.

It is worthy of remark that the produce of plot 19, like that of plots 11, where also the supply of phosphoric acid was relatively large, showed a comparatively high proportion of corn to straw, notwithstanding the deficient amount of total produce due to the relative exhaustion of potass in both cases. It may also be mentioned, that the straw has frequently been observed to be finer, the grain more thin-skinned, and the crop more evenly ripened, where the bone-ash has been acted upon by hydrochloric instead of sulphuric acid.

From the results of this series it may be concluded—that there is no practical or economical advantage in rendering bone-ash soluble by the expensive hydrochloric instead of the cheaper sulphuric acid; that rape-cake benefits the wheat crop by its supply of nitrogen and of mineral constituents, but immaterially by the supply of available carbon within the soil from decomposing organic matter; and that where a liberal phosphatic and nitrogenous manure was used for many years, the available supply of potass to the growing crop became very injuriously diminished.

Summary Statement of the Results of the last 12 Years.

1. The average annual produce of wheat per acre, over the last 12 of 20 years of the growth of the crop on the same land, and of more than 20 since the application of manure of any kind, was 15½ bushels of dressed corn, and there was no material diminution in the yield in the later years: the proportion of corn to straw was as high as in the produce by farmyard manure, and higher than in the majority of cases with the more productive artificial manures, but the weight per bushel of dressed corn was very low.

2. Farmyard manure, applied every year in amount containing considerably more of every constituent than was removed in the crop, increased the average annual produce to nearly 35½ bushels

of dressed corn, or by about 20 bushels per acre per annum, and gave the highest weight per bushel of dressed corn in the series, but the proportion of corn to straw was no higher than in the unmanured produce. The annual produce was very much higher during the latter than during the earlier half of the 20 years, but it increased much less rapidly during the last few years.

The questions arise—In what constituent, or class of constituents, was the unmanured land deficient? and—to what constituent, or class of constituents, supplied by the farmyard manure, was its increase of produce due?

3. A complex mineral manure (plot 5), supplying annually more of potass, soda, magnesia, lime, sulphuric acid, and phosphoric acid, than was taken off in the crops (but no silica), even though used after several years of accumulation of unexhausted residue from previous ammoniacal (and mineral) manuring, gave annually only about 3 bushels increase over the unmanured produce, and nearly 17 bushels less than the produce by farmyard manure. The proportion of corn to straw was, however, higher, but the weight per bushel of dressed corn lower, than in the produce by the farmyard manure.

4. Ammonia-salts alone (plot 10a), employed for 19 consecutive years after an application of mineral manure supplying of potass about as much as would be removed in the first 3, and of phosphoric acid about as much as would be removed in the first 5 of the 20 years, gave a considerable, but gradually diminishing, average annual increase (over the produce without manure)—amounting over the first 9 years to rather more than 9 bushels, over the last 10 to $7\frac{1}{2}$ bushels, and over the 12 to which our summary more particularly refers, to rather more than 7 bushels.

5. As ammonia-salts alone increased the produce very much more than mineral manure alone, and did so for a long series of years, it is obvious that the practically exhausted land contained a considerable excess of available mineral constituents relatively to the available supply of nitrogen from soil and atmosphere. The results further show, that the plants growing under the influence of a liberal artificial supply of mineral constituents appropriated scarcely any more nitrogen from natural sources than those growing on the unmanured land.

6. The same mineral manure which alone gave scarcely any increase, and the same amount of ammonia-salts (400 lbs.) which alone gave so much less increase than the farmyard manure, and in a diminishing rate from year to year, gave when employed together an average annual increase of about 21 bushels of corn and $22\frac{1}{2}$ cwt. of straw over the unmanured produce, or about 1 bushel of corn and 3 cwt. of straw over that by the farmyard manure. Larger additions of ammonia-salts to

the mineral manure gave larger amounts of increase, but at a very much diminished rate in proportion to the ammonia employed. Thus, a manure containing ammonia-salts and soluble mineral constituents, but neither silica nor organic matter yielding carbonic acid or other compounds of carbon within the soil, gave, for many consecutive years, more produce than an amount of farmyard manure supplying annually more of every mineral constituent, including silica, more nitrogen, and more carbon, than the total produce removed from the land.

7. Nitrate of soda, in amount containing about the same quantity of nitrogen as 400 lbs. of ammonia-salts, used in conjunction with the same mineral manure, gave nearly as much corn, and more straw and total produce, than the farmyard manure.

8. No beneficial effect resulted from the use as manure of organic matter yielding by decomposition carbonic acid, or other compounds of carbon, within the soil. In fact, although a crop of wheat equal to the average produce by farmyard manure would contain about 2000 lbs. of carbon, the plant seems practically independent of any supply of carbon by manure, being able to assimilate this large amount, either by its roots or its leaves, from the atmospheric sources, if only mineral constituents and nitrogen be supplied to the soil in sufficient quantity and in available form. Other cultivated plants of the Gramineous family, such as barley, and the grasses of our meadows and pastures, appear to be equally independent of a supply of carbon by manure. Root-crops, and probably some other of our agricultural plants are, on the contrary, very dependent on a supply of carbon from decomposing organic matter within the soil.

9. The carbonaceous organic matter of the farmyard manure used in the experiments, if not without effect, was obviously at any rate unnecessary; and the increase obtained by the use of that manure was no doubt mainly due to its large, but comparatively slowly available, supply of ammonia, or nitrogen in some other form, and mineral constituents.

IV. AMOUNT OF INCREASED PRODUCE OBTAINED FOR A GIVEN AMOUNT OF AMMONIA SUPPLIED IN MANURE.

It has been shown that full crops of wheat cannot be grown unless there be a liberal available supply of mineral constituents within the reach of the plant, and further, that such supply is ineffective unless ammonia, or nitrogen in some other available form, be also liberally provided within the soil. In our concluding observations reference will be made to the various means at the farmer's command of keeping up the necessary supplies of both the mineral constituents and nitrogen. But as the purchase

of ammoniacal manures and nitrates constitutes one of the recognised sources of nitrogen for the growth of wheat, the practical question arises—how much increase may be calculated upon from the use as manure of a given amount of ammonia, or of an equivalent amount of nitrogen in some other available form? Table XXXI. (see following page), brings together a vast amount of evidence on this point. It shows the amount of ammonia in manure (or of nitrogen as nitrate reckoned as ammonia) that was required for the production of 1 bushel (or 60 lbs.) increase of wheat grain, with its proportion of straw, on the most important plots, in each of the last 12 years of the experiments.

As the productive effect of a given amount of ammonia depends very much upon the available supply of the necessary mineral constituents within the soil, and as artificial nitrogenous manures of course should not be, and seldom are in practice, employed if the supply of them be deficient, the Table is arranged to show, not the amount of ammonia required for each bushel obtained beyond the produce without manure, but over that by the mixed mineral manure, which being higher, leaves so much the less to be reckoned as increase due to the action of the ammonia supplied. Then, again, instead of taking the actual number of bushels of increase of dressed corn each year, which would represent very different amounts according to the varying weight per bushel from year to year, the number of bushels is, in all cases, calculated by dividing the number of lbs. of increase of corn by 60. For the purposes of the Table, therefore, every 60 lbs. of increase over the produce by the mixed mineral manure is supposed to represent 1 bushel.

Many years ago, in papers in this Journal, we stated, as a provisional estimate deduced from the results of the experiments now under consideration so far as they had then proceeded, that the farmer might assume, for practical purposes, that he would, on the average of seasons, get 1 bushel of wheat and its proportion of straw beyond the produce of the soil and season, for each 5 lbs. of ammonia applied as manure for the crop. This estimate was founded upon results obtained where the mineral constituents were not unduly exhausted, and the amounts of ammonia supplied were not excessive; that is, under conditions likely to accord with those most frequently occurring in common practice.

The statement met with much ridicule from Baron Liebig, who said that it was "a mere stroke of fancy." Whether the statement in question, or this condemnation of it, partakes most of "a mere stroke of fancy," may be judged by the record of facts given in this Section.

50 lbs. of ammonia, or its equivalent of nitrogen, would be supplied in rather under 2 cwt. of commercial sulphate, or 1½

TABLE XXXI.—Quantity of Ammonia in Manure (or of Nitrogen as Nitrate reckoned as Ammonia) required to produce 1 bushel (= 60 lbs.) increase of Wheat-grain, and its proportion of Straw, according to the quantity applied per Acre, to the available supply of Mineral Constituents within the soil, and to the Season.

Plots.	Manures per Acre, per Annum, for 14 Years, 1852-65. (For further particulars see Appendix, Table IX., and Notes, pp. xviii-xx; and for Manures of 1852, see Appendix—Tables I-VIII., pp. i-xv.)	FIRST 6 YEARS.						SECOND 6 YEARS.						AVERAGE.		Plots.
		1852	1853	1854	1855	1856	1857	1858	1859	1860	1861	1862	1863			
		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	First 6 Years, 1852-57	Second 6 Years, 1858-63	
6 (a & b)	300 lbs. Ammonia-salts (1), and Mixed Mineral Manure (2)	12-45	7-13	4-37	4-76	5-68	4-05	4-79	5-40	8-95	4-17	4-66	4-56	5-39	4-38	6 (a & b)
7 (a & b)	400 lbs. Ammonia-salts, and Mixed Mineral Manure	10-43	7-66	4-31	6-25	5-61	4-35	4-66	7-23	8-76	5-19	5-35	5-73	5-86	4-95	7 (a & b)
8 (a & b)	600 lbs. Ammonia-salts, and Mixed Mineral Manure	14-49	11-47	5-70	10-43	7-23	5-32	6-13	11-82	10-54	7-67	6-64	5-98	8-01	6-90	8 (a & b)
13 (a & b)	800 lbs. Ammonia-salts, and Mixed Mineral Manure	17-37	13-08	7-03	13-54	9-76	7-06	7-99	16-20	13-59	9-11	10-72	5-07	9-98	9-00	13 (a & b)
17 (a & b)	400 lbs. Ammonia-salts, in alternate years, with Mixed Mineral Manure	12-09	..	4-67	..	7-96	..	6-26	..	10-72	..	9-90	..	6-92	6-47	17 (a & b) or 18 (a & b)
18 (a & b)	..	..	10-36	..	6-01	..	5-55	..	8-25	..	5-68	..	5-49	..	6-47	18 (a & b)
10 (a)	400 lbs. Ammonia-salts alone (19) years, 1850-53)	22-47	135-69	9-15	44-44	30-13	18-89	25-94	..	..	..	17-30	4-63	30-28	23-74	10 (a)
10 (b)	400 lbs. Ammonia-salts alone (13) years, 1851-53)	20-70	20-30	6-12	9-16	11-33	8-29	10-66	23-67	42-55	..	13-24	3-53	10-39	13-16	10 (b)
11 (a & b)	400 lbs. Ammonia-salts, and Superphosphate of Lime, and Sulphate of Soda	16-14	13-56	4-90	56-98	7-84	6-30	7-36	15-60	16-28	13-54	9-55	3-47	8-98	6-85	11 (a & b)
12 (a & b)	400 lbs. Ammonia-salts, Superphosphate of Lime, and Sulphate of Soda	13-50	8-25	4-29	6-73	6-79	4-70	4-93	7-40	8-68	5-96	6-33	3-72	6-39	5-94	12 (a & b)
13 (a & b)	400 lbs. Ammonia-salts, Superphosphate of Lime, and Sulphate of Soda	14-11	7-61	4-51	7-00	7-86	4-74	5-07	7-65	8-98	5-14	6-98	3-78	6-96	5-37	13 (a & b)
14 (a & b)	400 lbs. Ammonia-salts, Superphosphate of Lime, and Sulphate of Soda	12-90	8-16	4-45	6-71	6-16	4-70	4-93	7-61	9-18	5-54	7-30	3-73	6-31	5-31	14 (a & b)
9 (a)	500 lbs. Nitrate of Soda, and Mixed Mineral Manure (3)	9-63	23-68	8-33	7-67	7-39	4-69	5-10	11-30	6-99	5-47	8-90	2-68	6-59	4-73	9 (a)
9 (b)	500 lbs. Nitrate of Soda alone (3)	11-36	180-46	6-49	13-19	13-71	7-91	22-83	43-96	35-45	..	11-30	4-19	11-29	14-73	9 (b)

"Ammonia-salts"—equal parts Sulphate and Nitrate of Ammonia of commerce.

(1) "Mixed Mineral Manure"—Superphosphate of Lime, and Sulphates of Soda, Potash, and Magnesia.

(2) "Superphosphate of Lime"—1 pt. Bone-ash, and 3 parts Sulphuric Acid, Sp. gr. 1-7.

(3) "The Mixed Mineral Manure not applied until 1854-5, and only 475 lbs. Nitrate of Soda for 1859, and 275 lbs. for 1862 and 1864.

(4) "Only 475 lbs. of Nitrate of Soda for 1852.

cwts. of commercial muriate of ammonia, in about $2\frac{3}{4}$ cwts. of genuine Peruvian guano, or in rather more than $2\frac{1}{4}$ cwts. of nitrate of soda. These amounts are more than are usually employed in common practice for the wheat crop; and most practical men would consider double these quantities to be very heavy, if not excessive dressings.

In bringing to bear upon the question under consideration the additional experimental evidence now at command, we shall assume, therefore, that the results obtained by the use, per acre, of 50 or 100 lbs. of ammonia (or their equivalent of nitrogen as nitrate) most nearly represent those which may be expected in ordinary practice; and further, that the results obtained by these amounts in the cases where the mineral constituents (unless silica) are not in relative defect, are also such as are most likely to be obtained in ordinary farm practice. Accordingly, we adopt for our purpose, the results obtained on plots 6 with 200 lbs., and on plots 7 with 400 lbs. of ammonia-salts (containing, respectively, 50 and 100 lbs. of ammonia) in each case used in conjunction with the mixed mineral manure; and these will be taken as the standards by which to compare the effects of larger amounts of ammonia with the same mineral manure, or the same amounts of ammonia under less favourable conditions as to the supply of mineral constituents.

It will be observed, that, almost uniformly, rather less ammonia was required to produce 60 lbs. increase of corn on the average of the last 6, as compared with the first 6 of the last 12 years. It will, perhaps, be said that the apparently better effect during the later years is in reality due to the unexhausted residue of the supplies in the earlier years. Evidence enough has been adduced showing the limit of the effect of such unexhausted residue; and, whilst admitting that a portion of the difference in favour of the later years may be attributed to previous accumulation, there can be no doubt, as has been shown, that the last 6 seasons were themselves more favourable than the preceding 6, and that to this cause a considerable portion of the difference is really due. Subject, then, to some correction on the score of accumulation, the average result over the 12 years may doubtless be taken as pretty closely representing the average effect of a given amount of ammonia, according to the amount of it employed, and to the favourable or unfavourable condition of the soil in regard to the supply of mineral constituents.

When 50 lbs. of ammonia per acre were annually applied in conjunction with a complex mineral manure, excluding silica (plot 6), the average annual result was, that 4.86 lbs. of ammonia were required to produce 60 lbs. increase of corn, with its equivalent of straw. This amount of ammonia, as has been said,

is as much, if not more, than would be generally employed; and it is seen that, with it, the quantity expended for each bushel of increase was very nearly the previously assumed amount of 5 lbs. When double the quantity per acre was used, which would be much more than appropriate for most soils and seasons, rather more than 5 lbs. (5·37), when 3 times the amount 7·35 lbs., and when 4 times 9·47 lbs., were required. Thus, when excessive amounts of ammonia are employed, much more is expended for the production of a given amount of immediate increase of crop, than when only moderate quantities are used; and it has been seen how very slowly the excess may become available in after years.

Still more unfavourable was the result when 400 lbs. of ammonia-salts (equal 100 lbs. ammonia) were employed under defective conditions as to the supply of mineral constituents. On plots 17 and 18, on one or the other of which that amount was each year employed succeeding the application of the mixed mineral manure in the preceding year, it required 6·69 lbs. of ammonia to produce 60 lbs. of increase of corn with its proportion of straw. On plots 12, which might be deficient in available supply of magnesia and possibly of potass, on plots 13 which were probably relatively deficient in magnesia, and on plots 14 probably in the later years in potass, the amount of ammonia required was from 5·76 to 5·85 lbs. instead of only 5·37 lbs. on plots 7, where, with the same amount of ammonia-salts, the mineral manure each year supplied all three bases—potass, soda, and magnesia. Then again, on plots 11, to which no direct supply of either potass, soda, or magnesia, had been made throughout the 20 years (only small quantities in rape-cake) 8·57 lbs., on plot 10b, with a deficiency almost certainly of potass and phosphoric acid, and probably of magnesia also, 11·2 lbs.; and on plot 10a, with a still greater deficiency of mineral constituents, 21·57 lbs., or more than 4 times the normal amount of ammonia, were required to be provided for the production of 60 lbs. increase of corn, and its proportion of straw.

Very similar results were obtained when nitrogen, about equal in amount to that in 100 lbs. of ammonia, was supplied in the form of nitrate of soda, instead of ammonia-salts. When the nitrate was used year after year with the mixed mineral manure (plot 9a), it required nitrogen about equal to that in 5·41 lbs. of ammonia to produce 60 lbs. increase of corn and its proportion of straw, against 5·37 lbs. when ammonia-salts were used (plot 7). But when the same amount of nitrate was used without the mineral manure, an amount of nitrogen averaging about 12·8 lbs. of ammonia was annually expended to produce the same result.

It may be observed, too, that assuming the farmyard manure

to have contained only a moderate proportion of nitrogen, the amount expended for the production of a given quantity of increase corresponded to considerably more ammonia than was required when nitrogen equal to 50, or even 100 lbs., of ammonia was employed as ammonia-salts, or nitrate of soda, in conjunction with the mixed mineral manure, notwithstanding that the latter contained no silica, a constituent so liberally provided in the farmyard manure. It would appear, therefore, that the practical results have not yet been materially affected for want of available silica where the mixed mineral manure was employed. There is, however, evidence in our analytical results that silica has become relatively deficient where it has not been supplied in the manure.

Very striking indeed, then, is the difference of effect upon the immediate increase, of a given amount of nitrogen in manure, whether used as ammonia-salts or nitrate, according to the available supply of mineral constituents within the soil; and with the overwhelming evidence before him, which such a comprehensive summary of experimental results on the point affords, the practical man will not fail to see that he not only very injuriously further reduces his immediately available supply of mineral constituents, but also pays very dearly for his increase, if he seek to obtain it by means of purely nitrogenous manures, when his soil is already unduly exhausted of mineral constituents.

Equally, if not more, striking, is the difference of effect of a given amount of ammonia in one season as compared with another. Where the mineral condition is the most defective, there the result of a given amount of ammonia is the most reduced below the average in a bad season. Leaving the reader to the study of all such abnormal cases in the records given in the Table, it will be sufficient here to direct attention to the great difference of effect according to season even under the more favourable conditions as to the amount of ammonia employed, and as to the associated supply of mineral constituents.

The results of plot 6, where only 50 lbs. of ammonia were applied each year, and always in conjunction with the mixed mineral manure, will well illustrate the point in question. Whilst, taking the average of the 12 years, it required 4·86 lbs. of ammonia in manure to yield 60 lbs. of increase of corn and its proportion of straw, in the remarkably productive season of 1863 it required only 2·42 lbs., but in 1853, 7·13 lbs., in 1860, 8·85 lbs., and in 1852, 12·45 lbs. The amount of produce was, indeed, lower in 1853 than in 1852; but as the deficiency was very much greater with the mineral manure alone (upon the produce of which the increase is calculated) than where the

ammonia-salts were also used, the amount reckoned as increase due to the ammonia was by so much the greater in 1853, and hence the better result for a given amount of ammonia in that year than in 1852.

To conclude on this point: Great as is the difference of effect of a given quantity of ammonia, according to the amount applied per acre, to the mineral condition of the soil, and to the season, still, when only moderate quantities were used, when there was a sufficient supply of mineral constituents, and taking the average of many seasons—that is, under the conditions the most comparable with those of the average of common practice—the result was, in marked accordance with our early estimate, that almost exactly 5 lbs. of ammonia were required to be expended to obtain an increase of 1 bushel of wheat grain, and its proportion of straw.

V. CONCLUDING OBSERVATIONS; SHOWING THE PRACTICAL BEARINGS OF THE RESULTS.

Referring the reader to the fuller summaries already given, of the conclusions arrived at in reference to each separate branch of the subject, it only remains, in bringing this paper to a close, very briefly to recapitulate a few of the most prominent facts elicited, and to show their connexion with, and bearing upon, the ordinary farm practice of this country.

1. On a soil of not more than average wheat-producing quality, and taken for experiment after a course of 5 crops since the application of manure, wheat has been grown successfully, without manure, and with different descriptions of manure, for 20 years in succession.

2. Without manure, the produce of dressed corn was, in the first year, 15 bushels per acre; in the last, $17\frac{1}{2}$ bushels; and, taking the average of the 20 years, $16\frac{1}{2}$ bushels.

3. With farmyard manure, applied every year, the produce was, in the first year, $20\frac{1}{2}$ bushels; in the last, 44 bushels; and, on the average of the 20 years, $32\frac{1}{2}$ bushels.

4. With artificial manures, the highest produce was, in the first year, $24\frac{1}{2}$ bushels; in the last, $56\frac{1}{2}$ bushels; and, taking the average of the 20 years, $35\frac{1}{2}$ bushels, or considerably more than the average produce of Great Britain when wheat is grown in the ordinary course of agriculture in rotation; and also considerably more than was obtained in the same field by an annual application of farmyard manure.

5. Mineral manures alone, though applied in the soluble form, increased the produce scarcely at all; that is, they did not enable the plant in any material degree to assimilate more nitrogen and

carbon from atmospheric sources, than when it was grown on the practically exhausted unmanured land.

6. Nitrogenous manures alone, increased the produce very considerably for many years in succession; hence, the soil in its practically exhausted condition was relatively much richer in available mineral constituents, than in available nitrogen.

7. The largest crops were obtained when mineral and nitrogenous manures were employed together; and it was by such mixtures, even though they supplied no silica (nor carbon), that the produce by farmyard manure was far exceeded, although the latter supplied, not only both silica and carbon, but all other constituents in larger quantity than they were removed in the crops.

The question arises—Will any conclusions drawn from these results regarding the character of the exhaustion induced by a course of cropping in this particular soil, and consequently regarding the description of manure required before it will again produce full crops of wheat, be at all applicable to any other soil, or to soils generally?

Baron Liebig, although he profusely illustrates his own views by reference to field experiments, and even to isolated results of our own, if by unfair representation they can be made to serve his purpose, and although it is doubtless by the evidence of such experiments that he has been led to his present, and on many points greatly amended, views, at the same time denies the utility of field experiments generally, and of our own in particular, as a basis of deduction regarding even a neighbouring field, and, still more, a field in any other locality. Other authorities look at field experiments in a very different light. Only a few weeks since, in a lecture delivered before the members of the Highland and Agricultural Society of Scotland, at Stirling, Professor Anderson took as his subject the importance and the best mode of promoting field as well as other experiments in connexion with agriculture.

With regard to the particular soil upon which the experiments which form the subject of this Report were made, Baron Liebig, according to the exigency of his argument, has maintained alternately that it was so rich, and so poor, in mineral constituents, that it was utterly unfit for the purposes of our investigation. To aid the judgment of those who may wish to consider the subject in the spirit of candour proper to an important practical and scientific inquiry, it may be well to indicate how far the results, briefly stated above, are consistent with those obtained in direct experiments in an adjoining field, and on soils of very different descriptions in other localities, and also how far they are consistent with the common experience of practical agriculture in this country.

The following Table (see page 101) shows, side by side, the average annual produce obtained, without manure, by the "mixed mineral manure" alone, by 400 lbs. ammonia-salts alone, and by the "mixed mineral manure" and 400 lbs. ammonia-salts together—

1. During 8 years (1856-63) in the experimental field in which the results recorded in this paper were obtained.

2. During the same 8 years in an adjoining field, after several wheat crops had previously been taken without manure.

3. During 3 years (1852-54) at Holkham, in Norfolk, on a soil described as a light, thin, and rather shallow, brown sand-loam, but resting upon an excellent marl containing a large quantity of calcareous matter, and which had grown wheat in the preceding year with the same manures, and white turnips manured with farmyard dung and guano (of which both tops and roots were removed), in the year preceding the wheat.

4. Over 4 years (1856-59) at Rodmersham, Kent, on a soil described as a mixed clay, upon a chalk subsoil lying from 4 to 6 feet below the surface, and which had grown—in 1853, turnips manured with 2 cwts. of guano and 3 cwts. of superphosphate of lime per acre, the crop being fed on the land; in 1854, barley; and in 1855, beans with stable dung.

The coincidence of the results obtained in the two fields at Rothamsted is most striking; and when the known differences in the condition of the comparable plots in the two cases are taken into consideration, even the differences, such as they are, only afford additional evidence of the consistency of the indications. Thus, in Broadbalk field, the mineral manure alone succeeded heavy dressings of nitrogenous manure, whilst in the other it did not; and, accordingly, there is rather more produce in the former than in the latter. Again, the ammonia-salts had, in Broadbalk field, been used alone for several years on the same plot prior to the period taken into the calculation; and hence, with the greater exhaustion of mineral constituents in its case, there was rather less produce. The results without manure, and with the mixed mineral manure and ammonia-salts together, are so nearly identical in the two cases as to call for no remark.

The Holkham soil and subsoil were totally different in character to those at Rothamsted; the condition at the commencement as affected by recent manuring was rather higher, and two of the seasons over which the averages are taken were unfavourable, and one very favourable for the wheat crop. With these great differences of circumstance in almost every particular, we still find, as at Rothamsted, very little increase by mineral manure alone, considerably more by ammonia-salts alone, and more still by mixed mineral manure and ammonia-salts together.

The Rodmersham soil and subsoil were more nearly allied in

TABLE XXXII.—Results of Experiments on the GROWTH of WHEAT by different Manures, on different Soils, in different Localities, and in different Seasons.

MANURES APPLIED EACH YEAR.	AVERAGE ANNUAL RESULTS.			
	Rothamsted, 8 Years; 1856-63.		Holkham, Norfolk; 8 Years, 1852-54.	Rodmers- ham, Kent; 4 Years, 1856-59.
	Broadbalk Field.	Hoos Field.		
Dressed Corn, per Acre; in Bushels and Pecks.				
Unmanured	16 0	15 0	17 3½	25 2½
Mixed Mineral Manure, alone	19 0	16 0½	19 0½	28 2
Ammonia-salts, alone	23 0½	26 0½	27 0½	31 1½
Mixed Mineral Manure, and Ammonia-salts	38 1½	37 1½	32 2½	33 2
Weight per Bushel of Dressed Corn; lbs.				
Unmanured	57·0	57·7	61·3	59·4
Mixed Mineral Manure, alone	58·4	58·5	62·1	60·1
Ammonia-salts, alone	56·0	56·9	59·6	58·5
Mixed Mineral Manure, and Ammonia-salts	58·9	58·0	62·4	57·8
Total Corn, per Acre; lbs.				
Unmanured	990	926	1111	1565
Mixed Mineral Manure, alone	1192	987	1202	1760
Ammonia-salts, alone	1471	1618	1636	1917
Mixed Mineral Manure, and Ammonia-salts	2407	2295	2035	2020
Straw (and Chaff), per Acre; lbs.				
Unmanured	1625	1459	1298	3343
Mixed Mineral Manure, alone	1804	1528	1700	3949
Ammonia-salts, alone	2536	2705	2240	4788
Mixed Mineral Manure, and Ammonia-salts	4176	4016	2838	5696

character to those of Rothamsted; but the condition as affected by recent manuring was very much higher. In fact, the land, so far from being at the commencement in a practically exhausted condition requiring liberal manuring, was described as being already in a well cultivated and fertile state, and prepared for the wheat crop. The quantities of ammonia actually applied were, therefore, obviously very excessive. The result, under these circumstances, was, as might be expected, much higher produce

without manure, and smaller amounts of increase, especially of corn, with the nitrogenous manures. Still, the general character of the average results over the four years, is the same as in the other cases. There is but a small amount of increase by the mixed mineral manure alone, much more by ammonia-salts alone, and more still by the mixed mineral manure and ammonia-salts together.

But, independently of the evidence of direct experiment, such as is afforded in the results above referred to, we would here reiterate the opinion given in substance in former papers, and founded on a very extensive acquaintance with the practical experience of farmers in the use of artificial manures in every district of Great Britain for many years past, that, in 99 cases out of 100 in which wheat grown in the ordinary course of agriculture requires further manuring, it would be much more increased by the application of nitrogenous than of purely mineral manures; in other words, that in the ordinary course of agriculture with rotation, as practised in this country, the supply of mineral constituents immediately available for the wheat crop, is almost invariably in excess relatively to the immediately available supply of nitrogen from the atmosphere, or the accumulated stores within the soil itself. Furthermore, with few exceptions, the worse the so-called "condition" of the land, that is, the more it is in the agricultural sense exhausted, the more striking would be the effect of exclusively nitrogenous compared with that of exclusively mineral manures.

What, then, are the common practices of British agriculture which lead to this result?

Let us take as an example, as we have done before, the practice of the so-called four course rotation—of roots, barley, clover (or beans), and wheat. Let us further assume, for the sake of argument, that on the average 30 bushels of wheat, 35 bushels of barley, and the meat from the consumption of 10 tons of swedes, and clover equal to 6000 lbs. of clover hay (or 1500 lbs. of bean corn), are the products sold from each acre of the farm in the 4 years, and that the straw of the corn crops, and the excrements from the animals feeding on the roots and the clover or beans are retained on the farm as manure, and returned periodically to the land. Confining attention, for the sake of simplicity of illustration, to those mineral constituents which, so far as existing knowledge goes, are the most likely to become relatively deficient in the majority of soils, it may be estimated that, under such a course, the average annual loss per acre by the sale of corn and meat, would be of potass from $4\frac{1}{2}$ to 5 lbs., of phosphoric acid from 7 to 8 lbs., and of silica about 8 lbs.

But all practical men will admit that the amounts of produce here assumed to be exported from each acre, or equivalent amounts in other forms, could only be so under one of two conditions. Either the soil must be naturally a very fertile one, or the produce must be kept up by means of purchased cattle-food or artificial manures. In the case of a soil so fertile as to have yielded for any considerable number of years the average produce supposed without assistance from import, it may well be questioned whether it, with its workable subsoil, would not be competent to yield annually, by decomposition, the necessary amounts of the mineral constituents mentioned, and if of them of others also, for an all but indefinite period. In the other case—that in which the produce is kept up by means of the import of cattle-food or artificial manure, or of part one and part the other—the loss of the constituents in question derived from the soil itself will, of course, be by so much less than the amounts assumed above, and that of others will be also reduced. There can indeed be little doubt that, in actual practice, the loss to the soil itself, by the sale of corn and meat, is generally more nearly one-half, and frequently less than one-half, of the above assumed amounts of the constituents mentioned; and that of others will be less accordingly.

So far as the purchase of food for stock was relied upon, no selection could well be made from the current supplies in the market, that would not bring upon the farm more of the mineral constituents than the increase of produce due to the manure obtained from it would remove from the land in the form of corn and meat. In fact, to increase the sales of corn and meat by the import of cattle-food as generally practised, is to increase, and not to diminish, the amount of available mineral constituents within the soil. If, on the other hand, the produce were kept up by means of artificial manures, the rules of selection among intelligent practical men are such, that almost invariably much more of phosphoric acid at any rate, would be brought upon the land, than would be removed from it in the increase of corn and meat due to the use of the imported manures.

In the case supposed without import, it is probable that, in the majority of instances, phosphoric acid would be the most liable to become deficient in relation to other constituents. The sources of phosphoric acid developed in recent years, promise, however, to answer to any demand that seems likely to be made upon them to remedy such exhaustion of it as the present agricultural practices of the country induce.

In the case of imports, on the other hand, especially where they consisted chiefly of the current artificial manures rather than

of cattle-foods, potass would be the most likely to become deficient. The sources of potass in the market are, indeed, not large, and its price is high. Still, it would be a very economical manure if it increased the immediate produce by an amount containing anything like the proportion of that supplied, which is obtained in the case of nitrogen when nitrogenous manures are employed. But current practices have certainly not yet so far reduced the relative supply of potass in our soils as to render the application of direct potass-manures to the wheat crop at all profitable to the farmer. The results detailed in this paper clearly show, however, that salts of potass are effective enough on the growth of wheat when the immediately available supply within the soil is really unduly exhausted relatively to that of other mineral constituents, provided only that there be no deficiency of available nitrogen. In the case of Leguminous crops, indeed, potass-manures will frequently greatly increase the amount of nitrogen assimilated over a given area without any direct supply of the latter by manure. And should it happen that our modern system of town drainage should lead to such an exhaustion of our arable lands of their due proportion of available potass, that potass-manures from without should become really effective, there can be little doubt that a sufficient economical source of supply would soon supervene on such a demand.

There is, of course, no question, that if the manurial constituents resulting from the consumption of the corn and meat sent into our towns could be returned to the land whence they came, its produce would be considerably increased; for with the mineral constituents there would always be associated nitrogen, in amount which would serve to render effective a considerable portion of all, if not the whole of some, of those constituents. If, however, human excretal matters continue to be diluted with water to the extent recognised by the growing system of urban defecation, and if dilute liquid sewage cannot be distributed in small quantities over large areas at a much lower cost to the farmer than has yet been proposed, there is little hope that the manurial constituents derived from the human food sent into our towns can be re-distributed over the area from which they came. Indeed, having regard to the inapplicability of dilute liquid sewage to arable land, except in small quantities and at particular seasons, and to the assumed cost of distribution, it appears probable that the most profitable mode of utilisation of sewage will be, to limit the area by applying the greater part, if not the whole, to permanent or other grasses, laid down to take it the year round, trusting mainly to the periodically broken up rye-grass land,

and to the application to arable land of the solid manure resulting from the consumption of the sewage grass, for obtaining other produce than milk and meat by means of sewage.

In the illustrations given above, therefore, it is sought to convey an approximate idea, on the one hand of the utmost extent, and on the other of the probable limit, of the loss to which our arable soils are subject by the sale of corn and meat, supposing the mineral constituents be not returned to the land whence they came. Confining attention to this object, we necessarily leave out of view the cases in which roots, hay, or straw, are largely sold, for, in such, compensation is generally made by the return to the land of town manures of some kind. If this be not done the loss of mineral constituents will, of course, be very considerable.

In view of the facts above adduced, we think it may safely be concluded, that the modern practices of this country, taken as a whole, do not tend to the injurious exhaustion of the mineral constituents in anything like the degree that has been assumed by some. Further than this, we think the evidence is more in favour of the supposition that, in a great majority of our soils, they are, by the combined aid of progressive liberation, and of restoration from without, becoming, in the course of cultivation, richer rather than poorer in immediately available mineral constituents relatively to immediately available nitrogen. So far as this is attained at the expense of the constituents of the soil itself, there is, of course, the less to fall back upon within a given depth from the surface. But, it surely cannot be denied, that if there really is an annual liberation of mineral constituents in available form for the growth of plants, at least a portion of this may, with propriety, be sold off the farm for good and all.

The exact amount of annual loss of mineral constituents which any soil, with its workable subsoil, can permanently support without injury, cannot, indeed, be proved. But such evidence as is at command goes to show, that, under the conditions at present existing, the nature and extent of the loss to which our soils are subject are such, that the majority are deficient of available nitrogen rather than of available mineral constituents, so far as the requirements for full crops of the cereal grains are concerned.

Insisting strongly, then, as we have always done, upon the absolute necessity of a full supply of available mineral constituents within the soil, relatively to that of nitrogen, we still believe that, in the actually existing conditions of British agriculture, it is not they, but the available nitrogen, that is generally found to be relatively deficient.

What then, are the sources of available nitrogen within the soil, to which the farmer must look for the production of good crops of wheat?

In former papers in this Journal, we have pointed out that his chief means to this end was the adoption of a suitable rotation of crops—alternating with his corn the so-called “green,” “fallow,” or “fodder” crops, an important office of which it is to collect from natural sources, or to conserve on the farm in the form of manure, available nitrogen for the increased growth of the saleable cereal grains. We have further maintained that, as either by bare fallow, or a rotation of crops, with the consumption of the fallow crops and the retention of the straw on the farm, the accumulation of available mineral constituents will generally be in excess of the available nitrogen, it is the amount of the latter, rather than of the former, that will be the measure of the increased produce obtained by such means.

Baron Liebig's former views of the means by which our cereal crops were to be increased were, however, directly opposed to those here stated. He assumed that fertility was quite independent of the ammonia conveyed to the soil; that if only the necessary mineral constituents were supplied in sufficient quantity and in available form, our cultivated plants, Gramineous as well as Leguminous, would derive sufficient ammonia from the atmosphere; that the presence of ammonia in our manures was immaterial; indeed, that the entire future prospects of agriculture depended upon our being able to dispense with ammonia in our manures, therefore with animal manures, and hence with the bulky farmyard manure, and substitute for it artificial preparations.

Baron Liebig now fully admitting the inefficacy of the wheat-manure devised by himself, attributes its failure to the condition of insolubility in which the mineral constituents were provided in it; and having formerly treated the investigations of Professor Way on the properties of soils with much ridicule, he now passes a well merited eulogium on the important experiments and discoveries of that gentleman and Mr. H. S. Thompson, and alleges, that since it has been shown that certain soluble mineral substances become sufficiently insoluble when supplied to the soil, the want of the anticipated effect of his manures is completely explained. It is obvious, however, that those discoveries afford no explanation whatever of that failure; for if insolubility were the only bar to efficiency, the same constituents supplied in the soluble form should have the effect which Liebig's wheat manure was designed to produce. They should, in fact, enable the wheat-plant to assimilate sufficient nitrogen from the atmosphere for large crops. But the results of direct experiment recorded in this and former

papers, as well as the common experience of this country show, that those soluble mineral manures which are effective enough when available nitrogen is supplied within the soil, are entirely unavailing to yield any more than a very immaterial amount of increase in the absence of such supply.*

Very inconsistently, however, with the supposition that want of solubility was the defect of his mineral manure, Baron Liebig now maintains that progress in agriculture depends, not as before on being able to dispense with a rotation of crops, with nitrogenous manures in general, and with farmyard manure in particular, and to substitute it by artificial preparations, but upon a proper rotation of crops, the successful growth of fodder plants, the use of farmyard manure, and the accumulation of nitrogenous food within the soil, so very important for the perfect growth of the cereals.

Whilst thus adopting the views which we have maintained in opposition to his own for so many years past, and have supported by much experimental and other evidence in the pages of this Journal, he seeks to convey the impression to his readers that we have in reality advocated directly contrary opinions—that, in fact, in insisting upon the necessity of an accumulation of available nitrogen within the soil for the increased growth of the cereals, we assume that the chief source of that accumulation should be ammonia purchased from without. In illustration of the hopelessness of improvement in agriculture under such conditions, he points out how very inadequate are the supplies of nitrogen in the form of purchased manure from without to any largely increased growth of corn; a view in which we need hardly say we fully concur.

No doubt the supply of ammonia, or nitrogen in some other form, from without, limited as it is, is a very important adjunct

* Notwithstanding Baron Liebig's former ridicule of Professor Way's experiments, and his subsequent acknowledgment of the importance of his results only after it was generally admitted, and when it was found that they were essential as the basis of new views of his own, and that they served him to explain his previous error (in a manner, however, which is seen to be quite untenable), the following are the terms in which that acknowledgment is spoken of by Professor Hofmann in his capacity of International Reporter:—

"The correction of his error by Way, Liebig frankly and unhesitatingly accepted. His genius instantly appreciated the value of the English chemist's observation; and shed upon it so bright a light as may be said to have doubled its importance. Liebig, in fact, studied the new truth in all its bearings, supplied its most generally received interpretation, displayed its momentous consequences, elevated it to the rank of a law of nature, and embodied this law as one of the corner-stones of his great edifice."

"Probably, in all Liebig's illustrious career, no incident bears higher testimony than this to the vigour and fertility of his intellect, to his undeviating candour, and to his disinterested solicitude, on all occasions, for truth and truth alone." (Report of International Exhibition of 1862, p. 167.)

to that accumulated for the growth of the saleable cereal grains by means of rotation, and its associated practices. But we have long ago expressed our conviction that if the supplies of ammonia were much increased, the available mineral constituents of our soils would in their turn become relatively deficient.

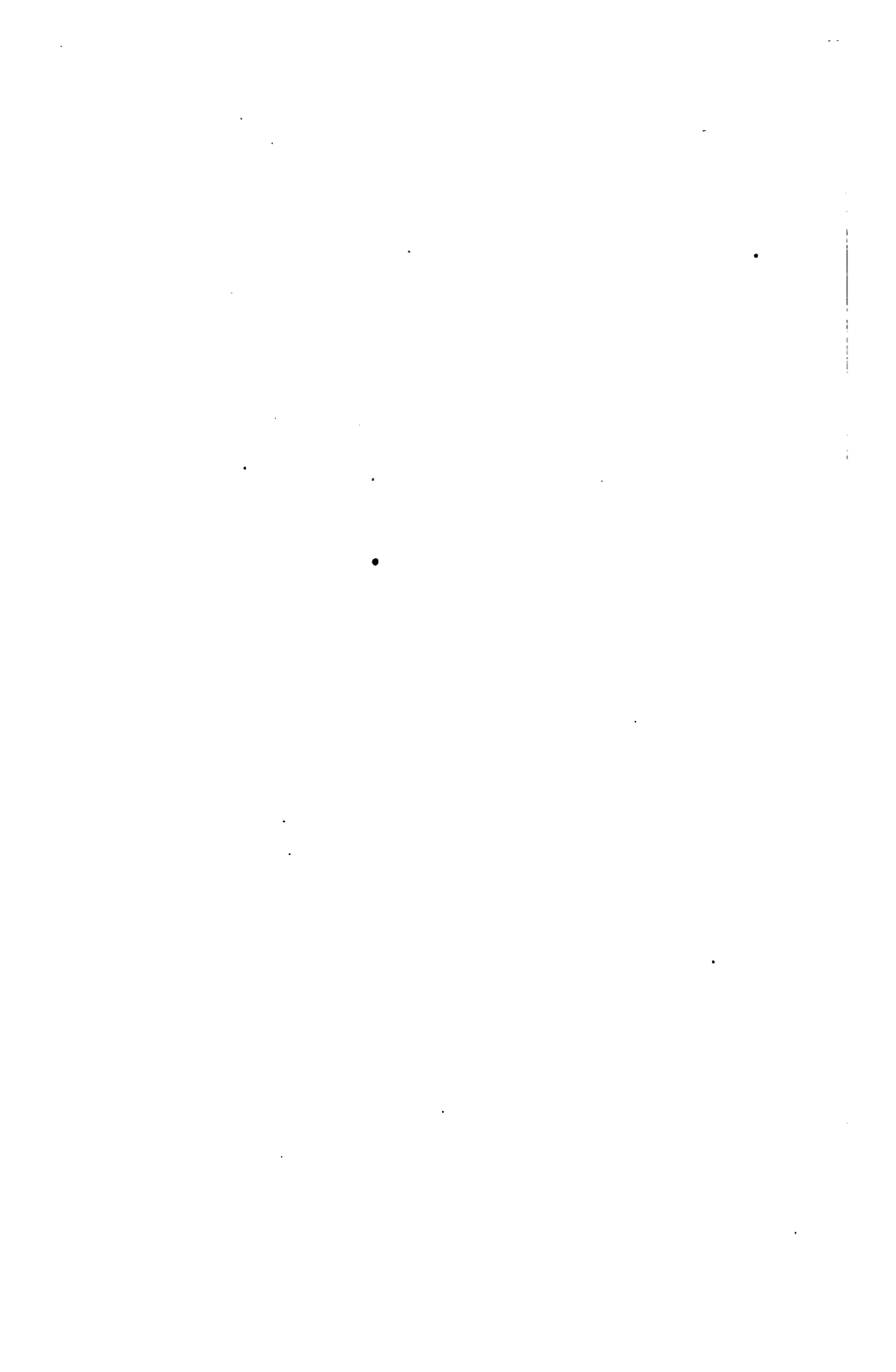
It is one thing to maintain, as we do, that under the existing conditions of agriculture in this country, the nitrogen in manures has justly a preponderating value attributed to it, and quite another to advocate as we do not, and never have done, that nitrogenous manures alone should be obtained from without. Nor is it the practice of intelligent farmers so to make use of the nitrogenous manures in the market. Those which the most nearly approach the character of purely nitrogenous manures, such as ammonia-salts and nitrate of soda, are rarely even for a single crop used alone, and never so by any farmer of moderate intelligence, unless—to say nothing of the periodical supplies of the home manures, perhaps enriched by the consumption on the farm of purchased food for stock—he applies specially phosphatic manure to some other crop in his course.

The objection that has been raised against the practice of purchasing food for stock, that that which is a gain of constituents to the purchaser is in the same degree a loss to the seller, surely in these days of growing intelligence, and of extension of commercial freedom and interchange of commodities throughout the world, hardly requires serious consideration. The producers in thickly-populated districts will reap the just reward of their folly if they dispose, without due compensation, of products which the requirements of their own markets, or of their own soils, render it desirable that they should keep at home. But, if countries thinly populated in relation to the area, and to the capabilities of the soils and climates with which they have to deal, should not supply the wants of those more densely peopled, in exchange for such commodities as they may need and their customers may be able to supply, because in so doing they would dispose of a portion of the mineral constituents annually liberated within their soils, the sooner this chemical principle of protection is understood and acted upon, and the sooner the commercial system of the world is abandoned, and we make up our minds to be satisfied with that which is produced at our own doors, the better we suppose will it be. For our own part, we are disposed to entertain some trust and confidence that the laws of supply and demand, if left unfettered by artificial restrictions, will in this, as in other matters, so regulate production as may best contribute to the wants of mankind at large.

Taking, however, the conditions of our agriculture as they really exist, and not anticipating a revolution in the sense just

supposed, we are disposed to consider that the relation of the supplies of potass and other mineral constituents, to those of phosphoric acid and nitrogen in the market and available from other sources, is such, that there is not much danger, except in isolated cases, of an excess of nitrogenous manure from without injuriously deranging that balance of constituents within the soil which it is essential to keep up, if not only full, but healthy, crops are to be produced. At present, at any rate, the produce per acre over the country at large is annually increasing rather than diminishing. The probability is, indeed, that any growing derangement in the composition of our soils will show itself in increasing tendency to abnormal growth, or disease of various kinds, rather than in gradual diminution of at the same time healthy crops. There is, however, as yet, so far as we are aware, no well-established evidence showing any clear connexion between the essential conditions of our modern system of cultivation, manuring, and cropping, on the one hand, and the prevalence of particular forms of faulty growth on the other.

Indeed, on many of our heavier soils, and even on lighter ones if purchased cattle-food be liberally employed, corn crops may be grown more frequently than is consistent with what have generally been considered the established rules of good farming, not only with pecuniary benefit to the producer, but without injury to the soil. On heavy soils barley of better quality may be obtained after wheat than after a root-crop. But when corn is taken after corn, great attention should be paid to the cleaning of the land, and manure should be liberally applied. When wheat follows another corn-crop, not less than 50 to 60 lbs. of ammonia (or its equivalent of nitrogen in some other form) should be applied per acre, and when barley or oats follow a corn-crop, from 40 to 50 lbs. The quantity of phosphate employed with the ammonia should be greater for spring than for autumn sown corn-crops. The manures should be applied at the time of sowing the seed.



APPENDIX.

APPENDIX.—TABLES.

EXPERIMENTS AT ROTHAMSTED ON THE GROWTH OF
APPENDIX.—TABLE I.—MANURES AND PRODUCE; 1ST SEASON, 1843-4.

Plots.	MANURES PER ACRE.								
	Farmyard Manure.	Farmyard Manure Ashes.	Silicate of Potass. ¹	Phosphate of Potass. ²	Phosphate of Soda. ²	Phosphate of Magnesia. ²	Super- phosphate of Lime. ³	Sulphate of Ammonia.	Rape Cake.
	Tons.	Cwts.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
0	Mixture of the residue of most of the other manures						..	..	..
1	..	..	..	..	..	..	700	..	154
2	14	..	..	..	..	..	..	..	..
3	Unmanured		..	..	..	..	..	..	..
4	..	32 ¹	..	..	..	..	..	..	..
5	..	..	..	..	..	..	700	..	..
6	..	..	..	..	..	420	350	..	..
7	..	..	..	..	325	..	350	..	..
8	..	..	..	375	..	..	350	..	..
9	..	..	..	..	..	..	630	65	..
10	..	..	220	..	..	..	560	..	..
11	..	..	..	..	..	..	350	..	308
12	..	..	..	..	162½	210	350	..	..
13	..	..	..	187½	..	210	350	..	..
14	..	..	275	..	..	210	350	..	..
15	..	..	110	150	..	168	350	..	..
16	..	..	110	75	65	84	350	65	..
17	..	..	110	75	65	84	350 ⁴	65	..
18	..	..	110	75	65	84	350	65	154
19	..	..	110	..	81	105	350	81	..
20	Unmanured		..	..	..	..	..	..	..
21	Mixture of the residue of most of the other manures						..	..	..
22									

¹ The farmyard dung was burnt slowly in a heap in the open air to an imperfect or coaly ash, and 32 cwts. of ash represent 14 tons of dung.

² The silicate of potass was manufactured at a glass-house by fusing equal parts of pearl-ash and sand. The product was a transparent glass, slightly deliquescent in the air, which was ground to powder under edge-stones.

³ The manures termed superphosphate of lime, phosphate of potass, phosphate of soda, and phosphate of magnesia, were made by acting upon bone-ash by means of sulphuric acid in the first instance, and in the cases of the alkali salts and the magnesian one neutralizing the compound thus obtained by means of cheap preparations of the respective bases. For the superphosphate of lime the proportions were 5 parts bone-ash, 3 parts water, and 3 parts sulphuric acid of sp. gr. 1·84; and for the phosphates of potass, soda, and magnesia, they were 4 parts bone-ash, water as needed, 3 parts sulphuric acid of sp. gr. 1·84, and equivalent amounts, respectively, of pearl-ash,

WHEAT YEAR AFTER YEAR ON THE SAME LAND.

MANURES AND SEED (Old Red Lammas) sown Autumn 1843.

Plots.	PRODUCE PER ACRE, &c.							INCREASE PER ACRE BY MANURE.			Offal Corn to 100 Dressed	Corn to 100 Straw.
	Dressed Corn.			Offal Corn. ⁵	Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn.	Straw and Chaff.	Total Produce.		
	Quantity. ³		Weight per Bushel.									
	Bush.	Pecks.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.		
0	19	3½	58·5	61	1228	1436	2664	305	316	621	..	85·5
1	16	3	59·0	52	1040	1203	2243	117	83	200	..	86·4
2	20	1½	59·3	64	1276	1476	2752	353	356	709	..	86·4
3	15	0	58·5	46	923	1120	2043	..	..	..	..	82·4
4	14	2½	58·0	44	888	1104	1992	-35	-16	-51	..	80·4
5	15	2½	58·3	48	956	1116	2072	33	-4	29	..	85·6
6	15	1	60·0	48	964	1100	2064	41	-20	21	..	87·6
7	15	2	60·3	49	984	1172	2156	61	52	113	..	84·0
8	15	0½	61·3	49	980	1160	2140	57	40	97	..	84·5
9	19	2½	62·3	64	1280	1368	2648	357	248	605	..	93·5
10	15	1½	62·0	50	1008	1112	2120	85	-8	77	..	90·6
11	17	0½	61·8	56	1116	1200	2316	193	80	273	..	93·0
12	15	2	61·5	50	1004	1116	2120	81	-4	77	..	90·0
13	16	1½	62·5	54	1072	1204	2276	149	84	233	..	89·0
14	15	3	61·3	51	1016	1176	2192	93	56	149	..	86·4
15	16	3½	62·0	55	1096	1240	2336	173	120	293	..	88·4
16	19	3½	62·5	65	1304	1480	2784	381	360	741	..	88·1
17	18	3½	62·3	62	1240	1422	2662	317	302	619	..	87·2
18	20	3½	62·0	68	1368	1768	3136	445	648	1093	..	77·4
19	24	1½	61·8	79	1580	1772	3352	657	652	1309	..	89·2
20	..	..	..	..	..	..	..	..	..	..	..	..
21	..	..	..	..	..	..	..	..	..	..	..	..
22	..	..	..	..	..	..	..	..	..	..	..	..

soda-ash, or a mixture of 1 part medicinal carbonate of magnesia and 4 parts magnesian limestone. The mixtures, of course, all lost weight considerably by the evolution of water and carbonic acid.

⁴ Made with unburnt bones.

⁵ In this first season neither the weight nor the measure of the offal corn was recorded separately; and in former papers the bushels and pecks of total corn (including offal) have erroneously been given as dressed corn. To bring the records more in conformity with those relating to the other years, 5 per cent., by weight, has been deducted from the total corn previously stated as dressed corn, and is recorded as offal corn; this being about the probable proportion, judging from the character of the season, the bulk of the crop, and the weight per bushel of the dressed corn. Although not strictly correct, the statements of dressed corn as amended in this somewhat arbitrary way will approximate more nearly to the truth, and be more comparable with those relating to other seasons, than those hitherto recorded.

EXPERIMENTS AT ROTHAMSTED ON THE GROWTH OF
APPENDIX.—TABLE II.—MANURES AND PRODUCE; 2ND SEASON, 1845.

Plots.	MANURES PER ACRE.											
	Farm-yard Manure.	Silicate of Potass. ¹	Phosphate of Potass. ²	Superphosphate of Lime. ³	Bone-ash.	Muriatic Acid.	Guano.	Sulphate of Ammonia.	Muriate of Ammonia.	Carbonate of Ammonia.	Rape Cake.	Tapoca.
	Tons.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
0	Mixture of the residue of most of the other manures									..	..	..
1	..	112	..	..	..	..	..	224	..	..	560	..
2	14	..	..	..	..	..	..	..	..	..	..	..
3	Unmanured											
4	..	..	..	..	112	112	..	112	..	..	..	..
5 ⁴	Unmanured											
6	..	..	..	112	..	..	..	112	..	..	560	..
7	..	..	..	112	..	..	..	112	..	..	..	560
8	..	..	..	..	..	..	..	112	..	..	560	..
9	..	..	..	..	..	..	..	168 ⁵	168 ⁵	..	..	..
10	..	..	..	..	..	..	..	168 ⁶	168 ⁶	..	..	..
11	..	..	..	280	..	..	..	224	..	..	560	..
12	..	..	280	..	..	..	..	224	..	..	560	..
13	..	..	..	..	..	..	336 ⁷	..	..	..	..	..
14	..	..	..	..	..	..	672 ⁸	..	..	..	..	..
15	..	..	..	..	224	224	..	224	..	..	..	..
16	..	..	..	224	..	..	..	56	56	..	560	..
17	..	..	..	224	..	..	..	112	112	..	280	..
18	..	..	..	336	..	..	..	112	112	..	..	..
19	..	..	..	..	112	112	..	112	..	..	336	..
20	Unmanured											
21	Mixture of the residue of most of the other manures									..	..	..
22												

¹ The silicate of potass was manufactured at a glass-house by fusing equal parts of pearl-ash and sand. The product was a transparent glass, slightly deliquescent in the air; it was ground to powder under edge-stones.

² The manures termed superphosphate of lime and phosphate of potass were made by acting upon bone-ash by means of sulphuric acid, and in the case of the potass salt neutralizing the compound thus obtained by means of pearl-ash. For the superphosphate of lime the proportions were 5 parts bone-ash, 3 parts water, and 3 parts sulphuric acid of sp. gr. 1·84; and for the phosphate of potass 4 parts bone-ash, water as needed, 3 parts sulphuric acid of sp. gr. 1·84, and an equivalent amount of pearl-ash. The mixtures, of course, lost weight considerably by the evolution of water and carbonic acid.

WHEAT YEAR AFTER YEAR ON THE SAME LAND.

MANURES and SEED (Old Red Lammas) sown March 1845.

Plots.	PRODUCE PER ACRE, &c.						INCREASE PER ACRE BY MANURE.			Offal Corn to 100 Dressed.	Corn to 100 Straw.
	Dressed Corn.		Offal Corn.	Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn.	Straw and Chaff.	Total Produce.		
	Quantity.	Weight per Bushel.									
	Bush. Pecks.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.		
0	32 0	56·5	159	1967	3977	5944	526	1265	1791	10·9	49·5
1	26 1½	54·8	248	1689	3699	5388	248	987	1235	17·3	45·7
2	32 0	56·8	151	1967	3915	5882	526	1203	1729	8·9	50·2
3	23 0½	56·5	131	1441	2712	4153	..	..	..	8·7	53·1
4	29 2½	58·0	161	1879	3663	5542	438	951	1389	9·4	51·3
5	22 2½	57·5	134	1431	2684	4115	-10	-28	-38	10·1	53·3
	26 3½	57·3	190	1732	3599	5331	291	887	1178	14·2	48·1
6	28 2½	57·8	214	1871	3644	5515	430	932	1362	14·1	57·3
7	26 2½	57·0	161	1682	3243	4925	241	531	772	11·3	51·9
8	27 0½	56·3	194	1716	3663	5379	275	951	1226	14·0	46·9
9	33 1½	58·3	187	2131	4058	6189	690	1346	2036	10·2	52·5
10	31 3½	56·3	191	1980	4266	6246	539	1554	2093	12·3	46·4
11	30 3	56·0	158	1880	4104	5984	439	1392	1831	11·3	45·8
12	28 2½	55·3	264	1842	4134	5976	401	1422	1823	17·8	44·5
13	25 0	56·3	152	1558	3355	4913	117	643	760	12·0	46·4
14	27 1	57·5	176	1743	3696	5439	302	984	1286	16·2	47·1
15	32 3½	57·5	209	2103	4044	6147	662	1332	1994	11·8	52·0
16	32 3½	56·3	182	2028	4191	6219	587	1479	2066	11·1	48·4
17	32 0½	55·8	299	2093	3826	5919	652	1114	1766	15·2	54·7
18	33 0½	56·5	180	2048	3819	5867	607	1107	1714	11·2	53·6
19	34 3	57·0	133	2114	4215	6329	673	1503	2176	9·1	50·2
20	24 2½	56·0	113	1495	3104	4599	54	392	446	9·7	48·2
21	..	..	..	..	..	..	..	..	..	..	..
22	..	..	..	..	..	..	..	..	..	..	..

² The medicinal carbonate of ammonia; it was dissolved in water and top-dressed.

⁴ Plot 5 was 2 lands wide (in after years, respectively, 5a and 5b); 5¹ consisting of 2 alternate one-fourth lengths across both lands, and 5² of the 2 remaining one-fourth lengths.

⁵ Top-dressed at once.

⁶ Top-dressed at 4 intervals.

⁷ Peruvian.

⁸ Ichaboc.

EXPERIMENTS AT ROTHAMSTED ON THE GROWTH OF
APPENDIX.—TABLE III.—MANURES AND PRODUCE; 3RD SEASON, 1845-6.

MANURES PER ACRE.															
Plots.	Farm-yard Manure.	Ash from 3 loads (3888 lbs.) Wheat-straw.	Liebig's Wheat-manure.	Peruvian Guano.	Silicate of Potass.	Pearl-ash.	Soda-ash.	Magnesian Lime-stone.	Superphosphate of Lime.			Sulphate of Ammonia.	Muriate of Ammonia.	Rape Cake.	
									Bone-Ash.	Sulphuric Acid (Sp. gr. 1.7).	Muriatic Acid.				
	Tons.		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
0	336	..	..	..	..	..	..	..	..	..	..
1	224	..	..	..	..	..
2	14	..	..	..	..	..	..	..	..	..	..	..	..	..
3	Unmanured	..	..	..	..	..	..	..	..	..	..	..	..	..
4	224	..	224	224	..	..
5a ¹	2	}	Straw-ash.	..	..	..	..	..	..	..	..	224 ¹	..	..
5b ¹				..	..	..	..	..	..	..	..	224 ¹	..	448
6a	448	..	..	..	..	..	..	..	..	..	..	..
6b	448	..	..	..	..	..	..	..	112	112	..	..
7a	448	..	..	..	..	..	..	..	..	..	..	448	
7b	448	..	..	..	..	..	..	..	112	112	448	..	
8a	224	..	..	..	..	448	
8b	224	..	..	112	112	..	
9a	448	
9b	224	..	448	
10a	224	..	..
10b	Unmanured	..	..	..	..	..	..	..	..	..	..	..	..	..
11a	224	224	..	..	..	448	
11b	224	224	..	112	112	..	
12a	180	..	224	224	..	..	..	448	
12b	180	..	224	224	..	112	112	..	
13a	200	..	..	224	224	..	..	..	448	
13b	200	..	..	224	224	..	112	112	..	
14a	84	..	224	224	..	..	..	448	
14b	84	..	224	224	..	112	112	..	
15a	224	..	224	224	..	448	
15b	224	..	..	..	224	..	224	224	..	448	
16a	67	60	84	224	224	..	..	..	448	
16b	67	60	84	224	224	..	224	..	448	
17a	67	60	84	224	224	..	112	112	448	
17b	67	60	84	224	224	..	224	..	..
18a	67	60	84	224	224	..	112	112	..	
18b	67	60	84	224	224	..	..	..	..
19	112	..	112	112	..	448	
20	}	Mixture of the residue of most of the other manures								
21															
22															

¹ Top-dressed in the Spring.

EXPERIMENTS AT ROTHAMSTED ON THE GROWTH OF

APPENDIX.—TABLE IV.—MANURES and PRODUCE; 4TH SEASON, 1846-7.

[illegible]

WHEAT YEAR AFTER YEAR ON THE SAME LAND.

MANURES and SEED (Old Red Lammas) sown end of October 1846.

Plots.	PRODUCE PER ACRE, &c.							INCREASE PER ACRE BY MANURE.			Official Corn to 100 Dressed.	Corn to 100 Straw.
	Dressed Corn.		Official Corn.	Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn.	Straw and Chaff.	Total Produce.			
	Quantity.	Weight per Bushel.										
	Bush.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.		
0	30	2½	61.1	156	2031	3277	5308	908	1375	2283	8.2	61.0
1	32	1	61.2	147	2119	3735	5854	996	1833	2829	7.2	56.7
2	29	3½	62.3	117	1981	3628	5609	858	1726	2584	6.2	54.6
3	16	3½	61.0	95	1123	1902	3025	..	..	..	8.9	59.0
4	27	1½	61.9	82	1780	2948	4728	657	1046	1703	4.7	60.3
5a	29	0	61.8	130	1921	3412	5333	798	1510	2309	7.1	56.3
5b	32	2	61.4	136	2132	3721	5853	1009	1819	2827	6.6	57.2
6a	24	3½	62.1	122	1663	2786	4449	540	884	1424	7.8	59.6
6b	24	1½	61.6	127	1632	2803	4435	509	901	1410	8.2	58.2
7a	27	3½	61.7	118	1834	3151	4985	711	1249	1960	6.8	58.2
7b	25	1½	61.5	125	1682	2953	4635	559	1051	1610	7.9	56.9
8a	32	1½	62.1	102	2115	3683	5798	992	1781	2773	5.5	57.4
8b	30	3	61.7	123	2020	3720	5740	897	1818	2715	6.3	54.3
9a	22	3	62.5	..	1477	2506	3983	228	604	..	..	53.9
9b	26	2	61.0	..	1755	3052	4807	632	1150	..	..	57.5
9c	26	0	61.3	123	1717	2858	4575	594	956	1550	..	60.1
10a	25	3	61.5	118	1702	2891	4593	579	989	1568	7.3	58.8
10b	25	2½	61.2	133	1705	2874	4579	582	972	1554	8.2	59.3
11a	30	3½	61.6	142	2044	3517	5561	921	1615	2536	6.3	59.5
11b	29	1½	61.8	123	1941	3203	5144	818	1301	2119	6.7	60.6
12a	29	2	62.0	124	1953	3452	5405	830	1550	2380	6.6	57.1
12b	27	0½	61.8	121	1796	3124	4920	673	1222	1895	7.1	57.4
13a	29	2½	62.5	108	1959	3306	5265	836	1404	2240	5.5	57.3
13b	27	1½	62.3	96	1801	3171	4972	678	1269	1947	5.3	56.7
14a	28	0½	62.8	175	1944	3362	5306	821	1460	2281	9.7	59.5
14b	26	3½	62.8	166	1856	3006	4862	733	1104	1837	9.8	61.7
15a	32	3	63.0	151	2214	3876	6090	1091	1974	3065	7.2	57.1
15b	32	0	62.6	137	2140	3617	5757	1017	1715	2732	6.6	59.1
16a	29	1½	62.3	132	1959	3417	5376	836	1515	2351	6.9	57.3
16b	34	2½	62.6	119	2283	4012	6295	1160	2110	3270	5.2	56.9
17a	33	3	62.3	119	2222	4027	6249	1099	2125	3224	5.6	55.1
17b	35	1½	62.0	117	2314	4261	6575	1191	2359	3550	6.4	54.3
18a	32	0½	62.7	142	2160	3852	6012	1037	1950	2987	6.9	56.0
18b	29	1½	62.9	181	2029	4164	6193	906	2262	3168	9.7	48.7
19	32	3	62.8	140	2195	4202	6397	1072	2300	3372	6.7	52.2
20	20	0½	62.5	70	1332	2074	3406	209	172	381	4.9	64.2
21	..	..	..	..	..	..	..	..	..	..	..	..
22	..	..	..	..	..	..	..	..	..	..	..	..

EXPERIMENTS AT ROTHAMSTED ON THE GROWTH OF

APPENDIX.—TABLE V.—MANURES and PRODUCE; 5TH SEASON, 1847-8.

[illegible]

WHEAT YEAR AFTER YEAR ON THE SAME LAND.

MANURES and SEED (Old Red Lammas) sown Autumn 1847.

Plots.	PRODUCE PER ACRE, &c.							INCREASE PER ACRE BY MANURE.			Offal Corn to 100 Dressed.	Corn to 100 Straw.
	Dressed Corn.		Offal Corn.	Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn.	Straw and Chaff.	Total Produce.			
	Quantity.	Weight per Bushel.										
	Bush. Pks.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.			
0	19 0 $\frac{1}{2}$	58.4	138	1259	2074	3333	307	362	669	13.4	60.7	
1	16 0 $\frac{1}{2}$	59.6	160	1124	1735	2859	172	23	195	16.3	64.7	
2	25 2 $\frac{1}{2}$	58.2	210	1705	3041	4746	753	1329	2082	13.8	56.0	
3	14 3	57.3	106	952	1712	2664	..	..	..	12.1	55.6
4	24 0 $\frac{1}{2}$	58.5	172	1583	2713	4296	631	1001	1632	12.0	58.3	
5a	29 3 $\frac{1}{2}$	59.2	144	1911	3266	5177	959	1554	2513	7.9	58.5	
5b	30 3 $\frac{1}{2}$	59.1	107	1932	3533	5465	980	1821	2801	5.8	57.5	
6a	24 3 $\frac{1}{2}$	58.8	214	1672	2878	4550	720	1166	1886	14.6	58.0	
6b	26 3	56.9	216	1737	2968	4705	785	1256	2041	14.0	58.5	
7a	30 3 $\frac{1}{2}$	59.4	106	1936	3083	5024	984	1376	2360	5.7	62.6	
7b	29 3 $\frac{1}{2}$	59.6	187	1963	3413	5376	1011	1701	2712	10.3	57.5	
8a	19 3	56.2	154	1263	2317	3530	311	605	916	13.6	54.5	
8b	19 0 $\frac{1}{2}$	59.4	127	1267	2148	3415	315	436	751	11.1	58.8	
9a	18 2 $\frac{1}{2}$	56.7	125	1181	1945	3126	229	233	462	11.6	60.7	
9b	25 0 $\frac{1}{2}$	58.3	208	1669	2918	4587	717	1206	1923	13.9	57.1	
10a	19 1	58.1	215	1334	2367	3701	382	655	1037	19.0	56.3	
10b	25 0 $\frac{1}{2}$	57.8	155	1604	2926	4530	652	1214	1866	10.6	54.8	
11a	29 1 $\frac{1}{2}$	59.6	233	1984	3274	5258	1032	1562	2594	13.1	60.6	
11b	24 3	57.9	207	1641	2898	4539	689	1186	1875	14.1	56.4	
12a	29 3	59.3	174	1988	3390	5328	986	1678	2664	9.3	57.2	
12b	26 0 $\frac{1}{2}$	59.2	167	1717	2880	4597	765	1168	1933	10.7	59.6	
13a	29 1 $\frac{1}{2}$	57.9	253	1955	3290	5245	1003	1578	2581	14.7	59.4	
13b	25 3 $\frac{1}{2}$	58.4	224	1780	3072	4802	778	1360	2138	14.6	56.3	
14a	28 0 $\frac{1}{2}$	58.8	184	1834	3257	5091	882	1545	2427	11.1	56.3	
14b	25 2 $\frac{1}{2}$	58.5	227	1726	2897	4623	774	1185	1959	15.1	59.5	
15a	22 3 $\frac{1}{2}$	58.1	242	1571	2937	4508	619	1225	1844	18.1	53.4	
15b	24 2 $\frac{1}{2}$	56.9	202	1607	3016	4623	655	1304	1959	14.1	53.2	
16a	29 3 $\frac{1}{2}$	60.0	184	1973	3115	5088	1021	1403	2424	10.2	63.3	
16b	30 1 $\frac{1}{2}$	58.4	171	1948	3380	5328	996	1668	2664	9.4	57.6	
17a	27 2 $\frac{1}{2}$	59.7	285	1933	3296	5229	981	1584	2565	17.0	58.6	
17b	28 3 $\frac{1}{2}$	59.7	222	1946	3324	5270	994	1612	2606	12.6	58.6	
18a	26 3	59.2	150	1734	2935	4669	782	1223	2005	9.2	59.0	
18b	26 2 $\frac{1}{2}$	59.6	215	1804	3056	4860	852	1344	2196	13.3	58.7	
19	29 1 $\frac{1}{2}$	56.2	185	1838	3295	5133	886	1583	2469	10.4	55.7	
20	16 0 $\frac{1}{2}$	58.3	111	1050	1721	2771	98	9	107	11.3	61.0	
21	..	..	..	..	..	..	..	..	..	..	..
22	..	..	..	..	..	..	..	..	..	..	..

EXPERIMENTS AT ROTHAMSTED ON THE GROWTH OF

APPENDIX.—TABLE VI.—MANURES and PRODUCE; 6TH SEASON, 1848-9.

[illegible]

WHEAT YEAR AFTER YEAR ON THE SAME LAND.

MANUBES and SEED (Red Cluster) sown Autumn 1848.

Ftols.	PRODUCE PER ACRE, &c.							INCREASE PER ACRE BY MANURE.			Offal Corn to 100 Dressed.	Corn to 100 Straw.
	Dressed Corn.		Offal Corn.	Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn.	Straw and Chaff.	Total Produce.			
	Quantity.	Weight per Bushel.										
	Bush.	Pks.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.			
0	..	..	..	..	..	..	..	..	..	..	..
1	..	..	..	..	..	..	..	..	..	..	..
2	31	0	63·8	107	2068	3029	5097	839	1415	2254	4·7	68·3
3	19	1	61·4	47	1229	1614	2843	..	..	..	3·9	76·1
4	30	0	63·0	110	2063	2645	4708	834	1031	1865	5·6	78·0
5a	37	1½	63·1	89	2446	3589	6035	1217	1975	3192	3·7	68·1
5b	39	3½	63·4	97	2651	3824	6475	1422	2210	3632	5·0	69·3
6a	36	1½	63·0	117	2410	3072	5482	1181	1458	2639	5·1	78·4
6b	37	3½	63·0	94	2484	3516	6000	1255	1902	3157	3·9	70·6
7a	38	2½	63·1	137	2576	3584	6160	1347	1970	3317	5·6	71·9
7b	37	3½	62·9	141	2531	3396	5927	1302	1782	3084	5·9	74·5
8a	22	3	61·7	76	1481	1815	3296	252	201	453	5·3	81·6
8b	31	2½	63·0	85	2080	3166	5246	851	1552	2403	4·3	65·7
9a	30	2½	62·8	111	2035	2683	4718	806	1069	1875	5·8	75·8
9b	22	1½	62·3	80	1475	1810	3285	246	196	432	5·7	81·5
10a	32	2½	62·3	112	2141	2851	4992	912	1237	2149	5·5	75·1
10b	32	1½	63·3	110	2157	2960	5117	928	1346	2274	5·3	72·9
11a	35	0½	62·6	121	2317	2892	5209	1088	1278	2366	5·6	80·1
11b	32	1½	63·0	112	2149	2942	5091	920	1328	2248	5·5	73·0
12a	35	3½	64·3	93	2396	3371	5767	1167	1757	2924	4·1	71·1
12b	34	1½	64·3	71	2277	3300	5577	1048	1687	2735	3·2	69·0
13a	34	3½	64·1	101	2340	3236	5576	1111	1622	2733	4·5	72·3
13b	34	2½	64·1	129	2346	3246	5592	1117	1632	2749	5·8	72·3
14a	34	1½	64·3	56	2266	3211	5477	1037	1597	2634	2·5	70·6
14b	31	1½	64·3	112	2123	3218	5341	894	1604	2498	5·5	66·0
15a	31	3½	64·2	65	2109	3038	5147	880	1424	2304	3·2	69·4
15b	30	0½	64·1	68	2005	3262	5267	776	1648	2424	3·5	61·5
16a	33	1½	64·5	101	2254	3384	5638	1025	1770	2795	4·7	66·6
16b	33	3½	64·6	75	2268	3559	5827	1039	1945	2984	3·4	63·7
17a	34	1	64·3	111	2316	3891	6207	1097	2277	3364	5·1	59·4
17b	33	1½	64·4	112	2259	3858	6117	1030	2244	3274	5·2	58·5
18a	32	1½	64·0	93	2163	3592	5755	934	1978	2912	4·5	60·2
18b	33	2½	64·0	95	2243	3779	6022	1014	2165	3179	4·4	59·3
19	29	2½	63·9	102	1994	3270	5264	765	1656	2421	5·4	61·0
20	..	..	..	..	..	..	..	..	..	..	..	..
21	..	..	..	..	..	..	..	..	..	..	..	..
22	..	..	..	..	..	..	..	..	..	..	..	..

EXPERIMENTS AT ROTHAMSTED ON THE GROWTH OF

APPENDIX.—TABLE VII.—MANURES AND PRODUCE; 7TH SEASON, 1849-50. After the MANURES AND SEED (Red Cluster)

Plots.	MANURES PER ACRE.									
	Farm-yard Manure.	Pearl-ash.	Soda-ash.	Sulphate of Magnesia.	Superphosphate of Lime.			Sulphate of Ammonia.	Muriate of Ammonia.	Rape Cake.
					Bone-ash.	Sulphuric Acid (Sp. gr. 1.7).	Muriatic Acid.			
	Tons.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
0	600	450	..	..	..	..
1	..	600	400	200	..	..	..	..	..	..
2	14	..	..	..	..	..	..	..	..	..
3	Unmanured	..	..	..	..	..	..	..	..	..
4	200	..	200	300	..	..
5a	..	300	200	100	200	150	..	250	250	..
5b	..	300	200	100	200	150	..	250	250	..
6a	..	300	200	100	200	150	..	200	200	..
6b	..	300	200	100	200	150	..	200	200	..
7a	..	300	200	100	200	150	..	200	200	500
7b	..	300	200	100	200	150	..	200	200	500
8a	200	200	..
8b	200	200	..
9a	200	200	..
9b	200	200	..
10a	200	200	..
10b	..	300	200	100	200	150	..	..	..	..
11a	200	150	..	200	200	..
11b	200	150	..	200	200	..
12a	..	300	..	..	200	150	..	200	200	..
12b	..	300	..	..	200	150	..	200	200	..
13a	..	300	..	..	200	150	..	200	200	..
13b	..	300	..	..	200	150	..	200	200	..
14a	..	300	..	..	200	150	..	200	200	..
14b	..	300	..	..	200	150	..	200	200	..
15a	..	300	200	100	200	..	200	300	..	..
15b	..	300	200	100	200	..	200	300	..	500
16a	..	300	200	100	200	150	..	200	200	..
16b	..	300	200	100	200	150	..	200	200	..
17a	..	300	200	100	200	150	..	200	200	..
17b	..	300	200	100	200	150	..	200	200	..
18a	..	300	200	100	200	150	..	200	200	..
18b	..	300	200	100	200	150	..	200	200	..
19	200	..	200	300	..	500
20	Unmanured	..	..	..	..	..	..	..	..	..
21)	Mixture of the residue of most of the other manures							..	..	..
22)								..	..	..

EXPERIMENTS AT ROTHAMSTED ON THE GROWTH OF
APPENDIX.—TABLE VIII.—MANURES AND PRODUCE; 8TH SEASON,

Plots.	MANURES PER ACRE.											
	Farm- yard Manure.	Cut Wheat- straw and Chaff.	Common Salt.	Sulphate of Potass.	Soda- ash.	Sulphate of Mag- nesia.	Superphosphate of Lime.			Sulphate of Ammo- nia.	Muriate of Ammo- nia.	Rape Cake.
							Bone- ash.	Sul- phuric Acid (Sp. gr. 1.7).	Muriatic Acid.			
	Tons.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
0	600	450	..	..	..	..
1	600	400	200	..	..	..	..	..	..
2	14	..	..	..	..	..	..	..	..	..	..	..
3	Unmanured	..	..	..	..	..	..	..	..	..	..	..
4	200	..	200	400	..	..
5a	300	200	100	200	150	..	300	300	..
5b	300	200	100	200	150	..	300	300	..
6a	300	200	100	200	150	..	200	200	..
6b	300	200	100	200	150	..	200	200	..
7a	300	200	100	200	150	..	200	200	1000
7b	300	200	100	200	150	..	200	200	1000
8a	..	5000	..	..	..	..	..	..	..	..	..	..
8b	300	200	100	200	150	..	100	100	..
9a	200	200	..
9b	200	200	..
10a	200	200	..
10b	200	200	..
11a	200	150	..	200	200	..
11b	200	150	..	200	200	..
12a	200	100	..	200	150	..	200	200	..
12b	200	100	..	200	150	..	200	200	..
13a	300	..	..	200	150	..	200	200	..
13b	300	..	..	200	150	..	200	200	..
14a	200	..	100	200	150	..	200	200	..
14b	200	..	100	200	150	..	200	200	..
15a	200	100	100	200	..	200	400	..	..
15b	200	100	100	200	..	200	300	..	500
16a	336 ¹	200	100	100	200	150	..	300	300	..
16b	200	100	100	200	150	..	300	300	..
17a	200	100	100	200	150	..	200	200	..
17b	200	100	100	200	150	..	200	200	..
18a	200	200	..
18b	200	200	..
19	200	..	200	300	..	500
20	Unmanured	..	..	..	..	..	..	..	..	..	..	..
21		..	..	..	..	..	..	..	..	..	..	..
22		..	..	..	..	..	..	..	..	..	..	..

¹ Top-dressed in March, 1851.

APP.]

Report of Experiment

WHEAT YEAR AFTER YEAR ON THE
1850-51. MANURES and SEED (Red Clay)

PRODUCE PER ACRE, &c.						
Plots.	Dressed Corn.		Offal Corn.	Total Corn.	Straw and Chaff.	
	Quantity.	Weight per Bushel.				
	Bush.	Pks.	lbs.	lbs.	lbs.	lbs.
0	18	3½	61·9	125	1296	186
1	18	1½	61·7	124	1251	184
2	29	2½	63·6	166	2049	309
3	15	3½	61·1	114	1083	162
4	28	0½	62·6	159	1919	294
5a	36	0	63·3	194	2473	413
5b	37	3½	63·3	213	2611	429
6a	33	1½	63·3	154	2271	362
6b	31	0½	62·3	189	2119	350
7a	36	3½	63·0	201	2524	458
7b	37	1½	63·0	178	2532	430
8a	26	0½	62·8	141	1785	276
8b	27	2½	62·6	137	1863	283
9a	31	1½	62·4	182	2142	325
9b	29	0½	62·0	170	1970	294
10a	28	3½	61·9	179	1966	307
10b	28	2½	62·5	149	1937	304
11a	32	2½	62·3	181	2216	338
11b	31	2½	62·5	181	2163	330
12a	32	3	63·1	165	2234	360
12b	32	2½	62·5	166	2203	358
13a	30	2½	62·6	180	2102	354
13b	30	3½	62·3	160	2083	344
14a	31	0½	62·9	168	2120	360
14b	31	0½	62·8	165	2121	353
15a	27	0½	62·7	138	1839	304
15b	30	2½	62	148	2077	343
16a	36	3½	63·5	161	2499	423
16b	36	2½	63·4	176	2501	433
17a	31	3½	63·3	131	2149	359
17b	30	2½	63·1	152	2079	340
18a	30	3½	63·0	139	2083	339
18b	31	0½	62·4	143	2090	358
19	30	1	62·4	144	2031	334
20	14	1	60·8	89	956	160
21	17	3½	61·9	127	1232	176
22						

NOTES TO TABLE IX. (p. xviii.)

[TABLE IX. is intended to be drawn out to the left, free of the book, as it has reference to the succeeding Tables.]

¹ *For the 16th and succeeding seasons*—the sulphate of potass was reduced from 600 to 400 lbs. per acre per annum on Plot 1, and from 800 to 200 lbs. on all the other Plots where it was used; the sulphate of soda from 400 to 200 lbs. on Plot 1, to 100 lbs. on all the Plots on which 200 lbs. had previously been applied, and from 550 to 336½ lbs. (two-thirds the amount) on Plots 12a and 12b; and the sulphate of magnesia from 420 to 280 lbs. (two-thirds the amount) on Plots 14a and 14b.

² *Plot 9a*—the sulphates of potass, soda, and magnesia, and the superphosphate of lime, were applied in the 12th and succeeding seasons, but not in the 9th, 10th, and 11th; and the amount of nitrate of soda was for the 9th season only 475 lbs. per acre, and for the 10th and 11th seasons only 275 lbs.

³ *Plot 9b*—in the 9th season only 475 lbs. of nitrate of soda were applied.

⁴ *Common salt*—not applied after the 10th season.

⁵ *Plots 17a and 17b, and 18a and 18b*—the manures on these plots alternate: that is, Plots 17 were manured with ammonia-salts in the 9th season; with the sulphates of potass, soda, and magnesia, and superphosphate of lime, in the 10th; ammonia-salts again in the 11th; the sulphates of potass, soda, and magnesia, and superphosphate of lime, again in the 12th, and so on. Plots 18, on the other hand, had the sulphates of potass, soda, and magnesia, and superphosphate of lime, in the 9th season; ammonia-salts in the 10th, and so on, alternately.

EXPERIMENTS AT ROTHAMSTED ON THE GROWTH OF WHEAT YEAR AFTER YEAR
ON THE SAME LAND.APPENDIX.—TABLE X.—PRODUCE of the 9TH SEASON, 1851-2. SEED (Red Cluster)
sown November 7, 1851; Crop cut August 24, 1852.

Plots.	PRODUCE PER ACRE, &c. (For the Manures see pp. xviii and xix).						INCREASE PER ACRE BY MANURE.			Oftal Corn to 100 Dressed.	Corn to 100 Straw.
	Dressed Corn.		Oftal Corn.	Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn.	Straw and Chaff.	Total Produce.		
	Quantity.	Weight per Bushel.									
	Bush. Pecks.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.		
0	15 0½	55.8	72	919	1706	2625	59	109	168	8.4	53.8
1	13 1	56.9	71½	825	1497	2322	— 35	— 100	— 135	9.4	55.1
2	27 2½	58.2	112½	1716	3457	5173	856	1860	2716	7.0	49.6
3	18 3½	56.6	78	860	1597	2457	..	..	..	9.9	53.9
4	13 1½	57.3	106½	870	1571	2441	10	— 26	— 16	18.9	55.4
5a	16 3	57.5	72½	1038	1903	2941	178	306	484	7.5	54.5
5b	17 0½	57.3	86½	1065	2032	3097	205	435	640	8.8	52.4
6a	20 3	57.6	95½	1288	2581	3869	428	984	1412	8.0	49.9
6b	20 2½	57.5	101½	1300	2604	3904	440	1007	1447	8.5	49.9
7a	26 2½	56.0	126½	1615	3850	5465	755	2253	3008	8.5	41.9
7b	26 3½	55.8	139½	1643	3772	5415	783	2175	2958	9.2	43.6
8a	27 3½	55.9	140½	1699	3806	5505	839	2209	3048	9.0	44.6
8b	27 0½	55.9	133½	1651	3772	5428	791	2175	2966	8.8	43.8
9a	25 2	55.6	171½	1591	3714	5305	781	2117	2848	12.1	42.8
9b	24 1½	55.3	153	1509	3374	4883	649	1777	2426	11.3	44.7
10a	21 3½	55.9	97½	1320	2787	4107	460	1190	1650	8.0	47.3
10b	22 0½	57.3	80	1343	2819	4162	483	1222	1705	6.3	47.6
11a	24 0½	55.6	128	1472	3081	4553	612	1484	2096	9.5	47.8
11b	22 1½	55.9	133½	1387	2912	4299	527	1315	1842	10.6	47.6
12a	24 1½	57.4	100½	1503	3257	4760	643	1660	2303	7.2	46.1
12b	24 1½	57.3	101½	1492	3232	4724	632	1635	2267	7.3	46.2
13a	24 0	57.5	100½	1480	3222	4702	620	1625	2245	7.3	45.9
13b	23 3½	57.1	106½	1476	3289	4765	616	1692	2308	7.8	44.9
14a	24 1½	56.9	114½	1507	3547	5054	647	1950	2597	8.2	42.5
14b	25 0½	56.7	107	1530	3607	5137	670	2010	2680	7.5	42.4
15a	23 1½	57.4	111½	1451	3212	4663	591	1615	2206	8.3	45.2
15b	25 0½	56.8	90½	1520	3421	4941	660	1824	2484	6.8	44.4
16a	28 3½	55.0	204½	1794	4677	6471	934	3080	4014	12.8	38.3
16b	28 0	54.5	175	1700	4616	6316	840	3019	3859	11.5	36.8
17a	25 2	56.5	135½	1577	3734	5311	717	2137	2854	9.4	42.2
17b	24 1½	56.9	132	1520	3466	4986	660	1869	2529	9.5	43.9
18a	13 3	57.0	86½	869	1687	2556	9	90	99	11.0	51.5
18b	14 3½	56.7	75	921	1764	2685	61	167	228	8.9	52.2
19	24 3½	56.1	183½	1582	3397	4979	722	1800	2522	13.1	46.6
20	14 0½	56.6	71	875	1577	2452	15	— 20	— 5	8.8	55.5
21	19 1½	56.9	68½	1177	2108	3285	317	511	828	6.2	55.8
22	19 2½	55.9	82½	1176	2179	3355	316	582	898	7.5	53.9

EXPERIMENTS AT ROTHAMSTED ON THE GROWTH OF WHEAT YEAR AFTER YEAR
ON THE SAME LAND.

APPENDIX.—TABLE XI.—PRODUCE OF THE 10TH SEASON, 1853. SEED (Red Rostock)
sown March 16; Crop cut September 10, and carted September 20, 1853.

Plots.	PRODUCE PER ACRE, &c. (For the Manures see pp. xviii and xix).						INCREASE PER ACRE BY MANURE.			Offal Corn to 100 Dressed.	Corn to 100 Straw.	
	Dressed Corn.		Offal Corn.	Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn.	Straw and Chaff.	Total Produce.			
	Quantity.	Weight per Bushel.										
	Bush.	Pks.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.			
0	9	0 $\frac{3}{4}$	49.1	142 $\frac{1}{2}$	599	1807	2406	240	394	684	31.1	33.1
1	6	1 $\frac{3}{4}$	46.1	100 $\frac{3}{4}$	404	1632	2036	45	219	264	33.2	24.8
2	19	0 $\frac{1}{2}$	51.1	143	1120	3372	4492	761	1959	2720	14.6	33.2
3	5	3 $\frac{1}{4}$	45.1	93	389	1413	1772	..	..	..	35.0	25.4
4	7	1	46.1	107	446	1670	2116	87	257	344	31.6	20.3
5a	10	0	48.9	99 $\frac{1}{2}$	587	1951	2538	228	538	766	20.5	30.1
5b	10	1	48.9	111 $\frac{1}{2}$	611	2130	2741	252	717	969	22.6	28.7
6a	16	3 $\frac{1}{2}$	51.8	112 $\frac{1}{2}$	978	2777	3755	619	1364	1983	13.0	35.2
6b	19	1	51.8	80 $\frac{1}{2}$	1072	2798	3870	713	1385	2098	8.1	38.3
7a	23	2 $\frac{1}{2}$	52.2	139	1369	3741	5110	1010	2328	3388	11.3	36.6
7b	23	2 $\frac{1}{2}$	51.1	132 $\frac{1}{2}$	1357	3734	5091	998	2321	3319	10.8	36.3
8a	22	1 $\frac{1}{2}$	51.1	191 $\frac{1}{2}$	1346	3966	5312	987	2553	3540	16.6	33.9
8b	24	2 $\frac{1}{2}$	51.1	150 $\frac{1}{2}$	1425	3927	5352	1066	2514	3580	11.8	36.3
9a	11	1	47.7	155 $\frac{1}{2}$	691	2399	3090	332	986	1318	29.0	28.8
9b	10	1 $\frac{1}{2}$	46.1	158 $\frac{1}{2}$	649	2253	2902	290	840	1180	32.2	28.8
10a	9	3 $\frac{1}{2}$	48.9	159 $\frac{1}{2}$	642	2049	2691	283	636	919	33.1	31.3
10b	15	2	49.8	127 $\frac{1}{2}$	896	2682	3578	537	1269	1806	16.6	33.4
11a	17	2	50.1	127 $\frac{1}{2}$	1015	2524	3539	656	1111	1767	14.4	40.2
11b	18	2 $\frac{1}{2}$	51.1	117	1073	2707	3780	714	1294	2008	12.3	39.7
12a	22	0	52.0	137 $\frac{1}{2}$	1283	3665	4948	924	2252	3176	12.0	35.0
12b	23	3 $\frac{1}{2}$	51.1	140 $\frac{1}{2}$	1375	3704	5079	1016	2291	3307	11.4	37.1
13a	22	1 $\frac{1}{2}$	52.1	179	1341	3704	5045	982	2291	3273	15.4	36.2
13b	23	2 $\frac{1}{2}$	51.1	169	1396	3912	5308	1037	2499	3536	13.8	35.7
14a	21	2	51.2	203 $\frac{1}{2}$	1322	3471	4793	963	2058	3021	18.2	38.1
14b	23	0 $\frac{1}{2}$	52.6	132 $\frac{1}{2}$	1347	3761	5108	988	2348	3336	10.9	35.8
15a	19	0	51.1	161 $\frac{1}{2}$	1143	3361	4504	784	1948	2732	16.5	34.0
15b	23	2 $\frac{1}{2}$	51.1	130 $\frac{1}{2}$	1351	3756	5107	992	2343	3335	10.7	36.0
16a	24	1 $\frac{1}{2}$	52.5	220	1496	4904	6400	1137	3491	4628	17.2	30.5
16b	25	3 $\frac{1}{2}$	52.5	186 $\frac{1}{2}$	1537	5019	6556	1178	3606	4784	13.8	30.6
17a	8	1 $\frac{1}{2}$	49.8	101 $\frac{1}{2}$	520	1996	2516	161	583	744	24.3	26.1
17b	8	3 $\frac{1}{2}$	48.9	102 $\frac{1}{2}$	539	2012	2551	180	599	779	23.5	26.8
18a	17	3 $\frac{1}{2}$	52.9	175	1111	3385	4496	752	1972	2724	18.7	32.8
18b	20	3	52.1	163 $\frac{1}{2}$	1256	3796	5052	897	2383	3280	15.0	33.1
19	19	1 $\frac{1}{2}$	52.6	147 $\frac{1}{2}$	1160	3213	4373	801	1800	2601	14.6	36.1
20	5	3 $\frac{1}{2}$	47.8	150	425	1659	2084	66	246	312	54.4	25.6
21	12	3 $\frac{1}{2}$	50.4	101 $\frac{1}{2}$	753	2181	2934	394	768	1162	15.6	34.5
22	10	1	49.4	86	592	1860	2452	233	447	680	17.0	31.8

EXPERIMENTS AT ROTHAMSTED ON THE GROWTH OF WHEAT YEAR AFTER YEAR
ON THE SAME LAND.

APPENDIX.—TABLE XII.—PRODUCE of the 11TH SEASON, 1853-4. SEED (Red Rostock)
sown November 12, 1853; Crop cut August 21, and carted August 31, 1854.

Notes.	PRODUCE PER ACRE, &c. (For the Manures see pp. xviii and xix).						INCREASE PER ACRE PER MANURE.			Official Corn to 100 Dressed.	Corn to 100 Straw.	
	Dressed Corn.			Official Corn.	Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn.	Straw and Chaff.			Total Produce.
	Quantity.	Weight per Bushel.	lbs.									
0	26	1½	61.0	59½	1672	2114	3786	313	— 23	290	3.7	79.1
1	24	1½	60.2	59½	1529	2531	4060	170	394	564	4.0	60.4
2	41	0½	62.5	103½	2675	4450	7125	1316	2313	3629	4.0	60.1
3	21	0½	60.6	82	1359	2137	3496	..	..	..	6.4	63.6
4	23	3½	61.1	61½	1521	2338	3859	162	201	363	4.2	65.1
5a	24	1½	61.0	91½	1578	2520	4098	219	383	602	6.1	62.6
5b	24	0	61.6	53	1532	2503	4035	173	366	539	3.6	61.2
6a	33	2½	61.8	103½	2186	3845	6031	827	1708	2535	5.0	56.8
6b	34	2½	61.8	100½	2239	4055	6294	880	1918	2798	4.7	55.2
7a	45	2½	61.9	131½	2950	5603	8553	1591	3466	5057	4.7	52.6
7b	45	1½	61.8	140½	2944	5496	8440	1585	3359	4944	5.0	53.6
8a	47	1½	61.4	152½	3065	6135	9200	1706	3998	5704	5.3	50.0
8b	49	2½	61.8	139½	3208	6117	9325	1849	3980	5829	4.6	52.4
9a	38	3	60.7	103½	2456	4142	6598	1097	2005	3102	4.4	59.3
9b	38	3½	60.7	118½	2480	4243	6723	1121	2106	3227	5.0	58.4
10a	34	1½	60.5	131½	2211	3597	5808	852	1460	2312	6.3	61.5
10b	39	0½	61.6	121½	2535	4468	7003	1176	2331	3507	5.0	56.7
11a	44	2	61.1	140½	2859	5147	8006	1500	3010	4510	5.2	55.6
11b	43	0½	61.2	117½	2756	5020	7776	1397	2883	4280	4.5	54.9
12a	45	3½	62.2	114½	2966	5503	8469	1607	3366	4973	4.0	53.9
12b	45	1½	62.2	115	2939	5473	8412	1580	3336	4916	4.1	53.7
13a	45	0½	62.2	106	2913	5398	8311	1554	3261	4815	3.8	54.0
13b	43	3½	62.2	130½	2858	5545	8403	1499	3408	4907	4.3	51.6
14a	45	1½	62.2	127½	2946	5552	8498	1587	3415	5002	4.5	53.1
14b	44	0½	62.2	120½	2863	5418	8281	1504	3281	4785	4.4	52.9
15a	43	1½	62.1	111½	2801	4898	7699	1442	2761	4203	4.1	57.3
15b	43	1	62.4	112½	2810	5273	8083	1451	3136	4587	4.2	53.3
16a	49	2½	61.7	173½	3230	6702	9932	1971	4565	6536	5.7	48.3
16b	50	0½	61.7	196½	3293	6635	9928	1934	4498	6432	6.3	49.6
17a	45	3	62.1	104	2948	5270	8218	1589	3133	4722	3.7	55.9
17b	42	2½	62.2	86½	2732	4897	7629	1373	2760	4133	3.3	55.8
18a	24	0	61.2	55½	1526	2418	3944	167	281	448	3.8	63.1
18b	23	2½	61.0	64½	1511	2377	3888	152	240	392	4.5	63.6
19	41	0½	61.7	122½	2666	4677	7343	1307	2540	3847	4.8	57.0
20	22	3	60.8	62	1445	2217	3662	86	80	166	4.5	65.2
21	32	0½	61.2	63½	2030	3440	5470	671	1303	1974	3.3	59.1
22	31	3	61.0	55½	1994	3340	5334	635	1203	1838	2.9	59.7

EXPERIMENTS AT BOTHERHAMSTED ON THE GROWTH OF WHEAT YEAR AFTER YEAR
ON THE SAME LAND.

APPENDIX.—TABLE XIII.—PRODUCE of the 12TH SEASON, 1854-5. SEED (Red Rostock)
sown November 9, 1854; Crop cut August 26, and carted September 2, 1855.

Plots.	PRODUCE PER ACRE, &c. (For the Manures see pp. xviii and xix).						INCREASE PER ACRE BY MANURE.			Offal Corn to 100 Dressed.	Corn to 100 Straw.
	Dressed Corn.		Offal Corn.	Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw)	Corn.	Straw and Chaff.	Total Produce.		
	Quantity.	Weight per Bushel.									
	Bush. Pecks.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.		
0	17 0	60.7	63	1096	1726	2822	24	— 61	— 37	6.1	63.5
1	18 2	60.5	57½	1179	1890	3069	107	103	210	5.1	62.4
2	34 2½	62.0	88½	2237	3845	6082	1165	2058	3223	4.1	58.2
3	17 0	59.2	65½	1072	1787	2859	..	..	..	6.5	60.0
4	18 2½	59.5	57½	1168	1832	3000	96	45	141	5.2	63.8
5a	18 2	59.9	46½	1157	1819	2976	85	32	117	4.2	63.6
5b	18 0½	60.1	51½	1143	1800	2943	71	13	84	4.7	63.5
6a	27 3	60.3	80½	1753	2837	4590	681	1050	1731	4.8	61.8
6b	28 1	60.9	87½	1811	3037	4848	739	1250	1989	5.1	59.6
7a	32 2½	59.4	142	2084	3911	5995	1012	2124	3136	7.3	53.3
7b	33 1½	59.5	154	2138	4158	6296	1066	2371	3437	7.8	51.4
8a	29 3	58.8	160	1909	3838	5747	837	2051	2888	9.2	49.7
8b	33 0½	58.7	205	2153	4342	6495	1081	2555	3636	10.5	49.6
9a	29 2½	58.3	203½	1932	3946	5878	860	2159	3019	11.8	49.0
9b	25 1½	57.3	152½	1605	3212	4817	533	1425	1958	10.5	50.0
10a	19 3½	57.1	145	1285	2512	3797	213	725	938	12.7	51.2
10b	28 0½	58.9	145	1805	3268	5073	733	1481	2214	8.7	55.2
11a	18 3	55.3	174	1210	2484	3694	138	697	835	16.8	48.7
11b	24 2½	56.3	193½	1580	3153	4733	508	1366	1874	14.0	50.1
12a	30 0½	59.5	151½	1940	3538	5478	868	1751	2619	8.5	54.8
12b	33 2	60.2	157	2172	4010	6182	1100	2223	3323	7.8	54.2
13a	29 0	59.9	187½	1924	3503	5427	852	1716	2568	10.8	54.9
13b	32 2	60.4	147½	2110	3870	5980	1038	2083	3121	7.5	54.5
14a	29 3	60.0	167½	1954	3577	5531	882	1790	2672	9.4	54.6
14b	33 1½	60.0	148½	2158	4008	6161	1086	2216	3302	7.4	53.9
15a	31 3½	60.0	119½	2030	3825	5855	958	2038	2996	6.3	53.1
15b	33 3	60.6	146½	2193	4222	6415	1121	2435	3556	7.2	52.0
16a	33 1½	58.2	160	2100	4534	6634	1028	2747	3775	8.3	46.3
16b	32 2	58.2	225½	2115	4991	7106	1043	3204	4247	12.0	42.4
17a	18 3½	60.8	78½	1227	1976	3203	155	189	344	6.8	62.1
17b	17 0½	60.3	77½	1110	1804	2914	38	17	55	7.5	61.5
18a	32 3½	60.9	122½	2127	4017	6144	1055	2230	3285	6.1	52.9
18b	33 1½	60.8	135½	2170	4215	6385	1098	2428	3526	6.7	51.5
19	30 0½	58.7	195½	1967	3851	5818	895	2064	2959	11.1	51.1
20	17 2½	61.1	76½	1155	1831	2986	83	44	127	7.1	63.1
21	24 1½	60.8	47	1533	2419	3952	461	632	1093	3.2	63.4
22	24 2½	60.1	70½	1553	2457	4010	481	670	1151	4.8	63.2

EXPERIMENTS AT ROTHAMSTED ON THE GROWTH OF WHEAT YEAR AFTER YEAR
ON THE SAME LAND.

APPENDIX.—TABLE XIV.—PRODUCE of the 13TH SEASON, 1855-6. SEED (Red Rostock)
sown November 13, 1855; Crop cut August 26, and carted September 8, 1856.

Plots.	PRODUCE PER ACRE, &c. (For the Manures see pp. xviii and xix).						INCREASE PER ACRE BY MANURE.			Offal Corn to 100 Dressed.	Corn to 100 Straw.
	Dressed Corn.		Offal Corn.	Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn.	Straw and Chaff.	Total Produce.		
	Quantity.	Weight per Bushel.									
	Bush. Pecks.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.		
0	18 1½	56·8	132½	1179	1969	3148	287	411	698	12·7	59·9
1	17 0½	56·3	135½	1102	1933	3035	210	375	585	14·0	57·0
2	36 1½	58·6	150	2277	4317	6594	1385	2759	4144	7·1	52·8
3	14 2	54·3	103½	892	1558	2450	..	..	..	13·1	57·3
4	16 1½	55·5	115½	1026	1731	2757	134	173	307	12·7	59·3
5a	18 3½	56·5	104½	1167	2012	3179	275	454	729	9·9	58·0
5b	20 1½	56·2	106½	1247	2122	3369	355	564	919	9·4	58·7
6a	27 1½	58·2	128½	1717	3050	4767	825	1492	2317	8·1	56·3
6b	28 0½	58·5	110½	1755	3093	4848	863	1535	2398	6·7	56·7
7a	37 1	58·0	152½	2312	4560	6872	1420	8002	4422	7·1	50·7
7b	36 2½	57·6	140½	2244	4398	6642	1352	2840	4192	6·7	51·0
8a	40 0½	56·8	228½	2507	5182	7689	1015	3624	5239	10·0	48·4
8b	37 3½	57·1	230½	2400	5089	7489	1508	3531	5039	10·6	47·2
9a	32 1½	57·2	168½	2019	3875	5894	1127	2317	3444	9·1	52·1
9b	26 0	56·3	214½	1679	3152	4831	787	1594	2381	14·6	53·3
10a	24 0½	55·6	162½	1505	2818	4323	613	1260	1873	12·1	53·4
10b	27 2½	57·2	145	1727	3168	4895	835	1610	2445	9·2	54·5
11a	31 3½	57·3	173½	2001	3517	5518	1109	1959	3068	9·5	56·9
11b	30 2½	57·5	183½	1946	3443	5389	1054	1885	2939	10·4	56·6
12a	33 3½	58·7	111½	2102	3847	5949	1210	2289	3499	5·6	54·7
12b	32 3½	58·8	145½	2079	3725	5804	1187	2167	3354	7·5	55·8
13a	32 1½	58·6	138	2036	3743	5779	1144	2185	3329	7·3	54·4
13b	30 3½	58·9	193	2008	3651	5659	1116	2093	3209	10·6	55·0
14a	35 0½	58·6	140½	2195	4202	6397	1303	2644	3947	6·9	52·2
14b	34 0½	59·0	145	2162	4117	6279	1270	2559	3829	7·2	52·5
15a	30 0½	59·1	142½	1923	3521	5444	1031	1963	2994	8·0	54·6
15b	32 0	59·4	143½	2045	3752	5797	1153	2194	3347	7·5	54·5
16a	38 0½	58·5	195½	2426	5529	7955	1534	3971	5505	8·8	43·9
16b	37 3	58·7	232½	2450	5467	7917	1558	3909	5467	10·5	44·8
17a	31 2½	59·0	116½	1983	3558	5541	1091	2000	3091	6·3	55·7
17b	30 1½	59·1	137½	1935	3465	5400	1043	1907	2950	7·7	55·9
18a	17 3½	57·8	107	1140	2012	3152	248	454	702	10·4	56·7
18b	18 0	57·7	93½	1131	1938	3069	239	380	619	9·0	58·3
19	32 1	58·9	157½	2059	3562	5621	1167	2004	3171	8·3	57·8
20	17 0½	57·7	83½	1075	1888	2963	183	330	513	8·4	57·0
21	22 1½	58·0	98	1398	2529	3927	506	971	1477	7·5	55·3
22	21 1½	57·8	109½	1351	2498	3849	459	940	1399	8·8	54·1

EXPERIMENTS AT ROTHAMSTED ON THE GROWTH OF WHEAT YEAR AFTER YEAR
ON THE SAME LAND.

APPENDIX.—TABLE XV.—PRODUCE of the 14TH SEASON, 1856-7. SEED (Red Rostock)
sown November 6, 1856; Crop cut August 13, and carted August 22, 1857.

Plots.	PRODUCE PER ACRE, &c. (For the Measures see pp. xviii and xix).						INCREASE PER ACRE BY MANURE.			Offal Corn to 100 Dressed.	Corn to 100 Straw.
	Dressed Corn.		Offal Corn.	Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn.	Straw and Chaff.	Total Produce.		
	Quantity.	Weight per Bushel.									
	Bush. Pecks.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.		
0	18 2½	59·0	86½	1181	1545	2726	- 55	- 32	- 87	7·9	76·5
1	17 2½	59·0	76	1118	1532	2650	- 118	- 45	- 163	7·3	73·0
2	41 0½	60·4	98½	2587	3323	5910	1351	1746	3097	4·0	77·9
3	19 3½	58·3	74½	1236	1577	2813	..	..	..	6·4	78·3
4	22 1½	58·8	67½	1386	1572	2958	150	- 5	145	5·1	88·2
5a	22 3½	59·0	56½	1409	1617	3026	173	40	213	4·2	87·2
5b	24 2½	58·8	66½	1512	1735	3247	276	158	434	4·6	87·1
6a	35 1½	59·9	92½	2211	2757	4968	975	1180	2155	4·4	80·2
6b	35 1½	59·8	78½	2193	2757	4950	957	1180	2137	3·7	79·6
7a	43 1½	60·5	160½	2782	3680	6462	1546	2103	3649	6·1	75·6
7b	46 1½	60·3	108½	2902	3891	6793	1666	2314	3980	3·9	74·6
8a	47 3	60·8	158½	3058	4297	7355	1822	2720	4542	5·5	71·2
8b	48 3½	60·6	169½	3129	4450	7579	1893	2873	4766	5·7	70·3
9a	48 3	60·1	135	2767	3867	6634	1531	2290	3821	5·1	71·6
9b	36 0½	58·0	121½	2220	2983	5203	984	1406	2390	5·8	74·4
10a	29 0½	58·0	125½	1816	2392	4208	580	815	1395	7·4	75·9
10b	34 2	58·6	163½	2185	2875	5060	949	1298	2247	8·1	76·0
11a	39 0	58·5	150	2432	2943	5375	1196	1366	2562	6·6	82·6
11b	39 0½	58·0	121½	2397	2920	5317	1161	1343	2504	5·4	82·1
12a	43 3½	60·4	100	2747	3647	6394	1511	2070	3581	3·8	75·3
12b	43 2	60·4	104½	2729	3583	6312	1493	2006	3499	4·0	76·2
13a	42 3	60·6	122½	2714	3707	6421	1478	2130	3608	4·7	73·2
13b	43 2	60·5	108½	2739	3647	6386	1503	2070	3573	4·1	75·1
14a	43 3	60·5	134½	2781	3658	6439	1545	2081	3626	5·1	76·0
14b	42 3½	60·3	113½	2699	3652	6351	1463	2075	3538	4·4	73·9
15a	42 1½	60·4	125½	2681	3687	6368	1445	2110	3555	4·9	72·7
15b	44 1½	60·0	96½	2765	3778	6543	1529	2201	3730	3·6	73·2
16a	48 3½	60·5	175	3131	4688	7814	1895	3105	5001	5·9	66·9
16b	50 0	60·5	169½	3194	4703	7897	1958	3125	5084	5·6	67·9
17a	26 2½	59·1	66½	1642	2058	3700	406	481	887	4·2	79·8
17b	25 3½	58·8	59½	1583	1940	3523	347	363	710	3·9	81·6
18a	41 0½	59·7	114½	2566	3443	6009	1330	1866	3196	4·7	74·5
18b	40 0½	59·8	124½	2519	3365	5884	1283	1788	3071	5·2	74·9
19	41 2½	59·5	123½	2600	3193	5793	1384	1616	2980	5·0	81·4
20	19 2½	58·4	62½	1213	1564	2777	- 23	- 13	- 36	5·5	77·6
21	24 0	60·6	81½	1538	1815	3353	302	238	540	5·6	84·8
22	23 0½	60·6	87½	1491	1807	3298	255	230	485	6·2	82·5

EXPERIMENTS AT ROTHAMSTED ON THE GROWTH OF WHEAT YEAR AFTER YEAR
ON THE SAME LAND.

APPENDIX.—TABLE XVI.—PRODUCE OF THE 15TH SEASON, 1857-8. SEED (Red Rostock)
sown November 3 and 11, 1857; Crop cut August 9, and carted August 20, 1858.

Plots.	PRODUCE PER ACRE, &c. (For the Measures see pp. xviii and xix).						INCREASE PER ACRE BY MANURE.			Offal Corn to 100 Dressed.	Corn to 100 Straw.	
	Dressed Corn.		Offal Corn.	Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn.	Straw and Chaff.	Total Produce.			
	Quantity.	Weight per Bushel.										
	Bush.	Pecks.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.			
0	20	3	61.2	61½	1332	1902	3234	191	232	423	4.8	70.0
1	16	1½	60.7	64½	1055	1630	2685	86	40	126	6.5	64.7
2	38	3½	62.6	82½	2512	3837	6349	1371	2167	3538	3.4	65.5
3	18	0	60.4	52	1141	1670	2811	..	..	..	4.8	68.3
4	19	0½	61.1	36½	1206	1673	2879	65	3	68	3.1	72.1
5a	18	2½	61.5	35	1187	1532	2719	46	138	92	3.0	77.5
5b	19	1	61.4	45	1227	1643	2870	86	27	59	3.8	74.7
6a	28	2½	62.1	41½	1818	2577	4395	677	907	1584	2.3	70.6
6b	29	0½	62.1	38½	1850	2713	4563	709	1043	1752	2.1	68.2
7a	38	2½	61.9	65	2450	3965	6415	1309	2295	3604	2.7	61.8
7b	39	2½	62.3	68	2530	4092	6622	1389	2422	3811	2.8	61.8
8a	41	3½	61.8	86½	2680	4667	7347	1539	2997	4536	3.3	57.4
8b	41	3½	61.7	94½	2675	4667	7342	1534	2997	4531	3.7	57.3
9a	37	2½	60.8	100	2384	4317	6701	1243	2647	3890	4.4	55.2
9b	23	2	58.8	88	1470	2688	4158	329	1018	1347	6.4	54.7
10a	22	3½	59.6	75½	1439	2130	3569	298	460	758	5.6	67.6
10b	27	3	61.4	70½	1775	2615	4390	634	945	1579	4.1	67.9
11a	30	3½	60.5	106½	1977	2797	4774	836	1127	1963	5.8	70.7
11b	33	0½	60.4	104	2099	3018	5117	958	1348	2306	5.2	69.6
12a	37	3½	62.1	78½	2437	3663	6100	1296	1993	3289	3.3	66.5
12b	37	0½	62.1	76½	2387	3673	6060	1246	2003	3249	3.3	65.0
13a	37	0½	62.1	72	2384	3693	6077	1243	2023	3266	3.1	64.6
13b	37	0½	62.7	66½	2397	3677	6074	1256	2007	3263	2.9	65.2
14a	37	3½	62.1	65½	2413	3737	6150	1272	2067	3339	2.8	64.6
14b	38	1½	62.0	61½	2436	3710	6146	1295	2040	3335	2.6	65.8
15a	35	1½	62.6	70½	2285	3515	5800	1144	1845	2989	3.2	65.0
15b	37	2	62.8	81½	2436	3698	6134	1295	2028	3323	3.5	65.9
16a	41	3	62.1	106½	2702	4797	7499	1561	3127	4688	4.1	56.3
16b	42	0½	62.1	99½	2717	4813	7530	1576	3143	4719	3.8	56.5
17a	33	1½	62.5	66½	2150	3203	5353	1009	1533	2542	3.2	67.1
17b	33	3½	62.5	65½	2181	3274	5455	1040	1604	2644	3.1	66.6
18a	22	3½	62.3	41½	1472	2006	3480	331	338	669	2.9	73.3
18b	20	2½	62.4	49½	1338	1967	3305	197	297	494	3.8	68.0
19	33	1½	62.5	93½	2177	3185	5362	1086	1515	2551	4.5	68.3
20	17	0	60.3	63½	1089	1730	2819	52	60	8	6.2	63.0
21	24	1½	61.5	70½	1574	2373	3947	483	703	1186	4.8	66.3
22	22	0	61.5	58½	1412	2180	3592	271	510	781	4.3	64.8

EXPERIMENTS AT ROTHAMSTED ON THE GROWTH OF WHEAT YEAR AFTER YEAR
ON THE SAME LAND.

APPENDIX.—TABLE XVII.—PRODUCE of the 16TH SEASON, 1858-9. SEED (Red Ros-
tock) sown November 4, 1858; Crop cut August 4, and carted August 20, 1859.

Nota.	PRODUCE PER ACRE, &c. (For the Manures see pp. xviii and xix).						INCREASE PER ACRE BY MANURE.			Official Corn to 100 Dressed.	Corn to 100 Straw.
	Dressed Corn.		Official Corn.	Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn.	Straw and Chaff.	Total Produce.		
	Quantity.	Weight per Bushel.									
	Bush. Pecks.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.		
0	21 2½	54.0	88½	1254	2310	3564	203	135	338	7.6	54.3
1	19 3	55.0	101	1189	2300	3489	138	125	263	9.3	51.7
2	36 0½	56.5	218½	2263	4810	7073	1212	2635	3847	10.7	47.1
3	18 1½	52.5	88½	1051	2175	3226	..	..	..	9.2	48.3
4	19 0½	55.0	131½	1188	2230	3418	137	55	192	12.5	53.3
5a	20 2½	56.0	123½	1277	2323	3600	226	148	374	10.7	55.0
5b	20 2½	56.0	118½	1273	2393	3666	222	218	440	10.2	53.2
6a	29 2½	56.5	133½	1808	3747	5555	757	1572	2329	8.0	48.3
6b	30 0½	56.5	153½	1855	3853	5708	804	1678	2482	9.0	48.1
7a	34 2½	55.9	158½	2097	4677	6774	1045	2502	3548	8.2	44.9
7b	34 2½	55.9	155	2089	4803	6892	1038	2638	3666	8.0	43.5
8a	34 3½	54.0	186½	2068	5353	7421	1017	3178	4195	9.9	38.6
8b	34 0½	53.4	181½	2007	5597	7604	956	3422	4378	10.0	35.9
9a	30 0	54.5	170½	1806	5270	7076	755	3095	3850	10.5	34.3
9b	24 2½	50.5	170	1412	3590	5002	361	1415	1776	13.7	39.3
10a	18 3½	51.5	230	1207	2730	3937	156	555	711	23.5	44.2
10b	25 2	52.5	160	1500	3420	4920	449	1245	1694	11.9	43.9
11a	26 3½	51.4	248½	1628	3527	5155	577	1352	1929	18.0	46.2
11b	27 3½	51.3	274½	1698	3577	5275	647	1402	2049	19.3	47.5
12a	34 2½	54.5	170½	2060	4550	6610	1009	2375	3384	9.0	45.3
12b	34 3½	54.8	206½	2115	4743	6858	1064	2568	3632	10.9	44.6
13a	34 0½	55.0	155½	2037	4737	6774	986	2562	3548	8.3	43.0
13b	34 3½	55.0	168½	2087	4807	6894	1036	2632	3668	8.8	43.4
14a	34 1½	54.5	175½	2054	4763	6817	1003	2588	3591	9.4	43.1
14b	34 2½	54.5	188½	2074	4700	6774	1023	2525	3548	10.0	44.1
15a	34 0½	55.0	171½	2053	4773	6826	1002	2598	3600	9.1	43.0
15b	35 0½	55.0	165	2095	4993	7088	1044	2818	3862	8.6	42.0
16a	34 3½	52.6	189½	2026	5927	7953	975	3752	4727	10.3	34.2
16b	34 1½	52.6	193	2005	5793	7798	954	3618	4572	10.7	34.6
17a	21 1½	55.0	73½	1247	2483	3730	196	308	504	6.3	50.2
17b	19 3	54.5	90	1168	2373	3541	117	198	315	8.3	49.2
18a	32 3½	55.5	153½	1973	4533	6506	922	2358	3280	8.4	43.5
18b	32 2	56.0	158½	1980	4650	6630	929	2475	3404	8.7	42.6
19	30 2	55.5	211½	1903	4023	5926	852	1848	2700	12.5	47.3
20	17 3½	52.5	102½	1039	2217	3256	-12	42	30	11.0	46.9
21	26 1½	54.0	115½	1538	3185	4723	487	1010	1497	8.1	48.3
22	24 0½	55.0	130	1460	2980	4440	409	805	1214	9.8	49.0

EXPERIMENTS AT ROTHAMSTED ON THE GROWTH OF WHEAT YEAR AFTER YEAR
ON THE SAME LAND.

APPENDIX.—TABLE XVIII.—PRODUCE of the 17TH SEASON, 1859-60. SEED (Red Rostock) sown November 17, 1859; Crop cut September 17 and 19, and carted October 5, 1860.

Plots.	PRODUCE PER ACRE, &c. (For the Manures see pp. xviii and xix).						INCREASE PER ACRE BY MANURE.			Offal Corn to 100 Dressed.	Corn to 100 Straw.
	Dressed Corn.		Offal Corn.	Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn.	Straw and Chaff.	Total Produce.		
	Quantity.	Weight per Bushel.									
	Bush. Pecks.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.		
0	14 1½	53.5	61½	826	1445	2271	88	— 14	74	8.0	57.2
1	12 1½	52.8	61	717	1380	2097	— 21	— 79	— 100	9.3	52.0
2	32 1½	55.5	72½	1864	3440	5304	1126	1981	3107	4.1	54.2
3	12 3½	52.6	62½	738	1459	2197	..	..	..	9.3	50.6
4	14 2	53.0	73½	832	1520	2352	94	61	155	9.7	54.7
5a	15 2½	54.0	56½	903	1580	2483	165	121	286	6.7	57.2
5b	16 0½	53.1	78	935	1660	2595	197	201	398	9.1	56.3
6a	21 0½	53.7	76½	1210	2183	3393	472	724	1196	6.8	55.6
6b	22 3½	54.2	88½	1326	2393	3719	588	934	1522	7.1	55.4
7a	27 3½	54.3	98½	1612	3003	4615	874	1544	2418	6.5	53.7
7b	27 2½	54.3	102	1597	3137	4734	859	1678	2537	6.8	50.9
8a	30 3	52.8	133½	1759	3880	5639	1021	2421	3442	8.2	45.3
8b	31 2½	52.3	129½	1787	3813	5600	1040	2354	3403	7.8	46.9
9a	32 2½	51.5	176½	1858	4777	6635	1120	3318	4438	10.5	38.9
9b	19 2½	48.5	205	1155	3130	4285	417	1671	2088	21.6	36.9
10a	15 0½	49.5	155	905	2213	3118	167	754	921	20.7	40.9
10b	18 2½	51.0	111½	1060	2360	3420	322	901	1223	11.8	44.9
11a	22 1½	51.0	128½	1270	2503	3773	532	1044	1576	11.2	50.8
11b	22 1½	51.2	161½	1307	2693	4000	569	1234	1808	14.1	48.5
12a	28 0½	53.4	146½	1648	3230	4878	910	1771	2681	9.8	51.0
12b	26 2½	53.5	155	1577	3087	4664	839	1628	2467	10.9	51.1
13a	26 0½	54.3	154½	1575	2998	4568	837	1534	2371	10.9	52.6
13b	27 0½	53.8	139	1600	3037	4637	862	1578	2440	9.5	52.7
14a	27 1½	53.7	114½	1583	3053	4636	845	1594	2439	7.8	51.9
14b	27 0½	53.2	121½	1563	3103	4666	825	1644	2469	8.5	50.4
15a	25 1½	53.8	146	1510	2877	4387	772	1418	2190	10.7	52.5
15b	28 0	54.0	100½	1614	3090	4704	876	1631	2507	6.7	52.2
16a	32 2	52.0	165	1856	4117	5973	1118	2658	3776	9.8	45.1
16b	32 3	51.7	193½	1889	4207	6096	1151	2748	3899	11.4	44.9
17a	24 0½	54.1	107½	1409	2700	4109	671	1241	1912	8.3	52.2
17b	26 1½	54.3	114½	1548	2970	4518	810	1511	2321	8.0	52.1
18a	15 1½	54.5	94½	929	1720	2649	191	261	452	11.3	54.0
18b	16 1½	54.6	73½	963	1743	2706	225	284	509	8.3	55.3
19	24 0½	53.0	158	1435	2743	4178	697	1284	1981	12.4	52.3
20	12 0½	51.5	99½	722	1433	2155	— 16	— 26	— 42	16.0	50.4
21	15 2	52.5	78	893	1746	2639	155	287	442	9.6	51.2
22	13 3½	53.8	102½	847	1567	2414	109	108	217	13.8	54.0

EXPERIMENTS AT ROTHAMSTED ON THE GROWTH OF WHEAT YEAR AFTER YEAR
ON THE SAME LAND.

APPENDIX.—TABLE XIX.—PRODUCE of the 18TH SEASON, 1860-1. SEED (Red Rostock)
sown November 5, 1860; Crop cut August 20, and carted August 27, 1861.

Plots.	PRODUCE PER ACRE, &c. (For the Manures see pp. xviii and xix).						INCREASE PER ACRE BY MANURE.			Offal Corn to 100 Dressed.	Corn to 100 Straw.
	Dressed Corn.		Offal Corn.	Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn.	Straw and Chaff.	Total Produce.		
	Quantity.	Weight per Buabel.									
	Bush. Peck.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.		
0	15 1½	57·6	116½	1001	1768	2769	265	514	779	13·2	56·6
1	12 3½	57·6	84	828	1387	2215	92	133	225	11·3	59·7
2	34 3½	60·5	92	2202	3101	5303	1466	1847	3313	4·4	71·0
3	11 1½	57·4	84½	736	1254	1990	..	..	..	13·0	58·7
4	11 3½	58·0	175	863	1330	2193	127	76	203	25·4	64·9
5a	15 1½	59·1	134½	1047	1493	2540	311	239	550	14·8	70·1
5b	15 1½	59·0	174½	1082	1610	2692	346	356	702	19·2	67·2
6a	27 1½	59·5	128½	1755	2573	4328	1019	1319	2338	7·9	68·2
6b	27 3½	59·4	167	1818	2683	4501	1082	1429	2511	10·1	67·8
7a	35 2½	59·0	167	2263	3501	5764	1527	2247	3774	8·0	64·6
7b	34 1½	59·0	161½	2183	3555	5738	1447	2301	3748	8·0	61·4
8a	36 0	58·3	190½	2290	3913	6203	1554	2659	4213	9·1	58·5
8b	34 0½	58·5	196½	2190	3795	5985	1454	2541	3995	9·8	57·7
9a	38 3	56·8	244½	2162	4445	6607	1426	3191	4617	12·8	48·6
9b	13 3	53·9	167½	909	2170	3079	173	916	1089	22·6	41·9
10a	12 3½	55·0	145½	854	1930	2784	118	676	794	20·5	44·2
10b	15 3½	55·5	148½	1033	2163	3196	297	909	1206	16·8	47·8
11a	23 1½	55·3	160½	1455	2577	4032	719	1323	2042	12·4	56·5
11b	25 0½	55·8	172	1578	2646	4223	842	1391	2233	12·2	59·7
12a	32 1½	58·1	129½	2009	3192	5201	1273	1938	3211	6·9	63·0
12b	33 1½	58·7	182	2144	3337	5481	1408	2083	3491	9·3	64·3
13a	38 1½	59·9	170½	2168	3318	5486	1432	2064	3496	8·5	65·4
13b	35 0	60·0	205	2304	3490	5794	1568	2236	3804	9·8	66·0
14a	38 0½	59·1	171½	2125	3377	5502	1389	2123	3512	8·8	62·9
14b	33 3½	59·3	160½	2178	3308	5476	1437	2049	3486	8·0	65·8
15a	34 1½	60·0	127½	2138	3318	5506	1452	2064	3516	6·2	65·9
15b	34 3	60·2	158½	2249	3478	5727	1513	2224	3737	7·6	64·7
16a	36 1½	58·0	222	2338	4423	6761	1602	3169	4771	10·5	52·8
16b	37 2	58·6	233	2432	4343	6775	1696	3089	4785	10·6	56·0
17a	19 1	59·3	89½	1229	1753	2982	493	499	992	7·9	70·1
17b	18 0½	59·1	92½	1166	1663	2829	430	409	839	8·6	70·1
18a	32 1½	59·6	119½	2050	3094	5144	1314	1840	3154	6·2	66·2
18b	33 1½	59·5	134½	2123	3324	5446	1386	2070	3456	6·8	63·8
19	32 2	58·8	197½	2107	3238	5345	1371	1984	3355	10·3	65·1
20	13 0½	57·9	111½	872	1468	2340	136	214	350	14·6	59·4
21	16 1½	58·2	152½	1109	1640	2749	373	386	759	15·9	67·6
22	19 2½	58·5	152½	1306	1957	3263	570	703	1273	13·2	66·7

EXPERIMENTS AT ROTHAMSTED ON THE GROWTH OF WHEAT YEAR AFTER YEAR
ON THE SAME LAND.

APPENDIX.—TABLE XX.—PRODUCE of the 19TH SEASON, 1861-2. SEED (Red Rostock)
sown October 25, 1861; Crop cut August 29, and carted September 12, 1862.

Plots.	PRODUCE PER ACRE, &c. (For the Manures see pp. xviii and xix).						INCREASE PER ACRE BY MANURE.			Offal Corn to 100 Dressed.	Corn to 100 Straw.
	Dressed Corn.		Offal Corn.	Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn.	Straw and Chaff.	Total Produce.		
	Quantity.	Weight per Bushel.									
	Bush. Pecks.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.		
0	19 3½	58·5	65	1228	2030	3258	232	317	549	5·6	60·5
1	16 2½	58·0	55½	1024	1748	2772	28	35	63	5·7	58·6
2	38 1½	61·0	107	2447	4195	6642	1451	2482	3933	4·6	58·3
3	16 0	57·8	73½	996	1713	2709	..	..	..	8·0	58·2
4	16 2½	58·5	75½	1049	1662	2711	53	-51	2	7·7	63·2
5a	17 3½	59·0	58½	1119	1840	2959	123	127	250	5·5	60·8
5b	17 2½	59·0	60½	1101	1860	2961	105	147	252	5·9	59·2
6a	27 2	59·5	78½	1715	2839	4554	719	1126	1845	4·8	60·4
6b	28 3½	59·8	76½	1797	3100	4897	801	1387	2188	4·4	58·0
7a	35 2½	59·8	92½	2200	3906	6106	1204	2193	3397	4·4	56·3
7b	36 0½	59·5	110½	2265	3913	6178	1269	2200	3469	5·2	57·9
8a	39 3	59·2	122½	2477	4723	7200	1481	3010	4491	5·2	52·4
8b	39 0½	59·0	141½	2452	4635	7087	1456	2922	4378	6·1	52·9
9a	43 1½	59·5	104½	2688	6050	8738	1692	4337	6029	4·0	44·4
9b	25 3½	56·3	186½	1641	3256	4897	645	1543	2188	12·8	50·4
10a	23 0½	56·5	154½	1457	2593	4050	461	880	1341	11·9	56·2
10b	24 3½	57·5	172½	1600	2843	4443	604	1130	1734	12·1	56·3
11a	26 2½	58·0	156	1706	2842	4548	710	1129	1839	10·1	60·0
11b	27 0½	58·0	166	1734	2873	4607	738	1160	1898	10·6	60·4
12a	34 1½	58·0	104½	2096	3649	5745	1100	1936	3036	5·2	57·4
12b	33 0½	58·0	99½	2025	3609	5634	1029	1896	2925	5·2	56·1
13a	31 3½	58·0	100½	1953	3589	5542	957	1876	2833	5·5	54·4
13b	32 2½	58·0	124½	2019	3672	5691	1023	1959	2982	6·6	55·0
14a	30 1½	58·0	120	1886	3397	5283	890	1684	2574	6·8	55·5
14b	32 0½	58·1	144½	2008	3550	5558	1012	1837	2849	7·7	56·6
15a	30 1½	58·3	101	1872	3396	5268	876	1683	2559	5·7	55·1
15b	32 2½	58·3	125	2029	3758	5787	1033	2045	3078	6·6	54·0
16a	36 1½	58·0	120½	2225	4527	6752	1229	2814	4043	5·7	49·2
16b	36 0½	57·5	155	2233	4497	6730	1237	2784	4021	7·5	49·7
17a	27 3½	58·1	128½	1747	3080	4827	751	1367	2118	7·9	56·7
17b	27 2½	58·1	85	1685	3077	4762	689	1364	2053	5·3	54·8
18a	18 1½	58·5	92	1168	1993	3161	172	280	452	8·6	58·6
18b	18 2½	58·5	102	1195	2140	3335	199	427	626	9·3	55·9
19	23 1½	57·2	143½	1479	2653	4132	483	940	1423	10·8	55·8
20	12 1½	57·3	108	818	1517	2335	-178	-196	-374	15·2	53·9
21	20 1½	58·1	90½	1273	2192	3465	277	479	756	7·6	58·1
22	20 0½	58·0	86½	1250	2180	3430	254	467	721	7·5	57·3

EXPERIMENTS AT BOTHERHAMSTED ON THE GROWTH OF WHEAT YEAR AFTER YEAR
ON THE SAME LAND.

APPENDIX.—TABLE XXI.—PRODUCE of the 20TH SEASON, 1862-3. SEED (Red Rostock)
sown November 17, 1862; Crop cut August 10, and carted August 18, 1863.

Plots.	PRODUCE PER ACRE, &c. (For the Manures see pp. xviii and xix).						INCREASE PER ACRE BY MANURE.			Offal Corn to 100 Dressed.	Corn to 100 Straw.
	Dressed Corn.		Offal Corn.	Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn.	Straw and Chaff.	Total Produce.		
	Quantity.	Weight per Bushel.									
	Bush. Pecks.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.		
0	22 0½	62·6	42½	1429	1825	3,254	302	225	527	3·1	78·3
1	20 3	62·8	31½	1334	1745	3,079	207	145	352	2·4	76·4
2	44 0	63·1	109½	2886	4279	7,165	1759	2679	4438	4·0	67·5
3	17 1	62·7	47½	1127	1600	2,727	..	..	..	4·4	70·4
4	20 1	62·3	41½	1303	1654	2,957	176	54	230	3·3	78·8
5a	19 2½	63·0	46½	1283	1687	2,970	156	87	243	3·4	76·1
5b	19 3	63·0	52½	1296	1768	3,064	169	168	337	4·2	73·3
6a	39 1½	62·3	69½	2522	3714	6,236	1395	2114	3509	2·8	67·9
6b	39 3	62·3	58½	2534	3716	6,250	1407	2116	3523	2·4	68·2
7a	53 1½	62·6	140½	3477	5853	9,330	2350	4253	6603	4·2	59·4
7b	54 0	62·5	132½	3507	5878	9,385	2380	4278	6658	3·9	59·7
8a	56 2½	62·3	145½	3668	6715	10,383	2541	5115	7656	4·1	54·6
8b	54 3½	62·3	144½	3559	6489	10,048	2432	4899	7321	4·2	54·8
9a	55 2½	62·1	128½	3576	6312	9,888	2449	4712	7161	3·6	56·7
9b	41 1½	62·5	134	2723	4197	6,920	1596	2597	4193	5·2	64·9
10a	39 0½	62·6	134½	2587	3481	6,068	1460	1881	3341	5·5	74·3
10b	43 2½	62·8	123½	2858	4056	6,914	1731	2456	4187	4·5	70·5
11a	45 0	62·5	167	2979	4233	7,212	1852	2633	4485	5·9	70·4
11b	46 2	62·1	171½	3060	4459	7,519	1933	2859	4792	5·9	68·6
12a	54 2½	62·1	133½	3533	5443	8,976	2406	3843	6249	3·9	64·9
12b	53 1	62·2	141½	3454	5365	8,819	2327	3765	6092	4·3	64·4
13a	53 1	62·6	119	3453	5739	9,192	2326	4139	6465	3·6	60·2
13b	53 1½	62·5	107½	3439	5799	9,238	2312	4199	6511	3·2	59·3
14a	54 1½	62·5	125½	3527	5459	8,986	2400	3859	6259	3·7	64·6
14b	53 1½	62·5	110½	3450	5299	8,749	2323	3699	6022	3·3	65·1
15a	48 1½	62·5	95½	3114	5162	8,276	1987	3562	5549	3·2	60·3
15b	48 0	62·9	109	3127	5113	8,240	2000	3513	5513	3·6	61·2
16a	56 2½	62·4	175½	3710	7007	10,717	2583	5407	7990	5·0	53·0
16b	55 0½	62·3	172½	3607	6725	10,332	2480	5125	7605	5·0	53·6
17a	21 0½	62·8	42	1870	1918	3,288	243	318	561	3·2	71·4
17b	21 1½	62·8	46	1889	1903	3,292	262	303	565	3·4	73·0
18a	46 1½	62·6	105½	3006	4883	7,889	1879	3283	5162	3·6	61·6
18b	46 0½	62·8	111½	3009	4728	7,737	1882	3128	5010	3·8	63·6
19	46 2½	62·9	118	3054	4523	7,577	1927	2923	4850	4·0	67·5
20	17 2½	62·5	32	1137	1472	2,609	10	-128	-118	2·9	77·3
21	27 2½	62·5	69½	1796	2483	4,279	669	883	1552	4·0	72·4
22	29 3	62·4	52½	1907	2692	4,599	780	1092	1872	2·8	70·9

EXPERIMENTS AT ROTHAMSTED ON THE GROWTH OF

APPENDIX.—TABLE XXII.—DRESSED CORN.

HARVEST.											
Plots.	1844. ¹	1845.	1846.	1847.	1848.	1849.	1850.	1851.	1852.	1853.	1854.
	bush. pks.	bush. pks.	bush. pks.	bush. pks.	bush. pks.	bush. pks.	bush. pks.	bush. pks.	bush. pks.	bush. pks.	bush. pks.
0	19 3½	32 0	28 1½	30 2½	19 0½	..	19 1½	18 8½	15 0½	9 0½	26 1½
1	16 3	26 1½	22 0½	32 1	16 0½	..	..	18 1½	13 1	6 1½	24 1½
2	20 1½	32 0	27 0½	29 3½	25 2½	31 0	28 2	29 2½	27 2½	19 0½	41 0½
3	15 0	23 0½	17 8½	16 3½	14 3	19 1	15 3½	15 8½	13 8½	6 3½	21 0½
4	14 2½	29 2½	25 8½	27 1½	24 0½	30 0	27 3	28 0½	13 1½	7 1	23 3½
5a)		22 2½	19 0½	29 0	29 8½	37 1½	29 8½	36 0	16 3	10 0	24 1½
5b)	15 2½	26 3½	23 2½	32 2	30 3½	39 8½	30 3	37 3½	17 0½	10 1	24 0
6a)			30 0½								
6b)	15 1	28 2½	29 0½	24 1½	26 3	37 3½	29 3½	31 0½	20 3½	19 1	34 2½
7a)			22 3½	27 3½	30 3½	38 2½	32 1	36 3½	26 2½	23 2½	45 2½
7b)	15 2	26 2½	31 3	25 1½	29 3½	37 3½	32 0½	37 1½	26 3½	23 2½	45 1½
8a)			22 3½	32 1½	19 3	23 3	28 3	26 0½	27 3½	22 1½	47 1½
8b)	15 0½	27 0½	29 0½	30 3	19 0½	31 2½	30 1	27 2½	27 0½	24 2½	49 3½
9a)			23 2½	22 3	18 2½	30 2½	30 1½	31 1½	25 2	11 1	38 3
9b)	19 2½	33 1½	28 3½	26 0	25 0½	22 1½	27 2½	29 0½	24 1½	10 1½	38 3½
10a)			27 1½	25 3	19 1	32 2½	26 3½	28 3½	21 3½	9 3½	34 1½
10b)	15 1½	31 3½	17 2½	25 2½	25 0½	32 1½	17 3½	28 2½	22 0½	15 2	39 0½
11a)			23 1½	30 3½	29 1½	35 0½	30 3½	32 2½	24 0½	17 2	44 2
11b)	17 0½	30 3	30 0½	29 1½	24 3	32 1½	29 1½	31 2½	22 1½	18 2½	43 0½
12a)			24 1½	29 2	29 3	35 3½	29 3½	32 3	24 1½	22 0	45 3½
12b)	15 2	28 2½	28 2½	27 0	26 0½	34 1½	30 3½	32 2½	24 1½	23 3½	45 1½
13a)			24 0	29 2½	29 1½	34 3½	31 3½	30 2½	24 0	22 1½	45 0½
13b)	16 1½	25 0	29 1½	27 1½	25 3½	34 2½	30 1½	30 3½	23 3½	23 2½	43 3½
14a)			23 2½	28 0½	28 0½	34 1½	31 1½	31 0½	24 1½	21 2	45 1½
14b)	15 3	27 1	26 2½	26 8½	25 2½	31 1½	31 1½	31 0½	25 0½	23 0½	44 0½
15a)			31 1½	32 8	22 3½	31 3½	26 0½	27 0½	23 1½	19 0	43 1½
15b)	16 3½	32 3½	27 2½	32 0	24 2½	30 0½	30 3½	30 2½	25 0½	23 2½	43 1
16a)			23 3	29 1½	29 3½	33 1½	33 2½	36 3½	28 3½	24 1½	49 2½
16b)	19 3½	32 3½	30 1	34 2½	30 1½	33 3½	33 3	36 2½	28 0	25 3½	50 0½
17a)			33 2½	33 3	27 2½	34 1	31 1	31 3½	25 2	8 1½	45 3
17b)	18 3½	32 0½	30 2	35 1½	28 3½	33 1½	29 2½	30 2½	24 1½	8 3½	42 2½
18a)			31 0	32 0½	26 3	32 1½	29 8½	30 3½	13 3	17 3½	24 0
18b)	20 3½	33 0½	21 1	29 1½	26 2½	33 2½	28 2½	31 0½	14 3½	20 3	23 2½
19	24 1½	34 8	28 3	32 3	29 1½	29 2½	29 0	30 1	24 3½	19 1½	41 0½
20	..	24 2½	..	20 0½	16 0½	..	14 0	14 1	14 0½	5 3½	22 3
21	..	..	..	..	..	..	..	..	19 1½	12 3½	32 0½
22	..	..	..	..	..	..	..	17 3½	19 2½	10 1	31 3

¹ See foot-note No. 5, to Appendix Table I. p. iii.² For Plots 0, 1, 20, 21, and 22 the averages are for only 19, 18, 17, 13, and 13 years respectively.³ On Plots 17 and 18 the manures have alternated during the last 12 years; that is, ammonia-salts on Plots 17, and the mixed mineral manure on Plots 18, in one year; mineral manure on Plots 17, and ammonia-salts on Plots 18, in the next year, and so on.

WHEAT YEAR AFTER YEAR ON THE SAME LAND.

in BUSHELS and PECKS, per Acre, per Annum.

HARVESTS.										AVERAGE		Plots.										
1855.		1856.		1857.		1858.		1859.		1860.			1861.		1862.		1863.		Of 20 Years, 1844-63.	Of last 12 Years, 1852-63.		
bush.	pks.	bush.	pks.	bush.	pks.	bush.	pks.	bush.	pks.	bush.	pks.	bush.	pks.	bush.	pks.	bush.	pks.	bush.	pks.			
17	0	18	1½	18	2½	20	3	21	2½	14	1½	15	1½	19	3½	22	0½	20	1½	18	1	0
18	2	17	0½	17	2½	16	1½	19	3	12	1½	12	8½	16	2½	20	3	18	1	16	1½	1
24	2½	36	1½	41	0½	38	8½	36	0½	32	1½	34	8½	38	1½	44	0	32	1½	35	1½	2
17	0	14	2	19	3½	18	0	18	1½	12	3½	11	1½	16	0	17	1	16	1	15	2	3
18	2½	16	1½	22	1½	19	0½	19	0½	14	2	11	8½	16	2½	20	1	20	2½	16	3½	4
18	2	18	3½	22	3½	18	2½	20	2½	15	2½	15	1½	17	3½	19	2½	22	0½	18	1	5a
18	0½	20	1½	24	2½	19	1	20	2½	16	0½	15	1½	17	2½	19	3	23	1	18	2½	5b
27	3	27	1½	35	1½	28	2½	29	2½	31	0½	27	1½	27	2	39	1½	27	1½	27	3½	6a
28	1	28	0½	35	1½	29	0½	30	0½	22	3½	27	3½	28	3½	39	3	28	1½	28	3	6b
32	2½	37	1	43	1½	38	2½	34	2½	27	3½	35	2½	35	2½	53	1½	33	1½	36	1	7a
33	1½	36	2½	46	1½	39	2½	34	2½	27	2½	34	1½	36	0½	54	0	33	3	36	2½	7b
29	3	40	0½	47	3	41	8½	34	3½	30	3	36	0	39	3	56	2½	32	2	37	3½	8a
33	0½	37	3½	48	3½	41	8½	34	0½	31	2½	34	0½	39	0½	54	3½	33	1½	38	0½	8b
29	2½	32	1½	43	3	37	2½	30	0	32	2½	33	3	43	1½	55	2½	31	1½	34	2	9a
25	1½	26	0	36	0½	23	2	24	2½	19	2½	13	3	25	3½	41	1½	26	0½	25	3½	9b
19	3½	24	0½	29	0½	22	3½	18	3½	15	0½	12	3½	23	0½	39	0½	24	0	22	2½	10a
28	0½	27	2½	34	2	27	3	25	2	18	2½	15	3½	24	3½	43	2½	25	3½	26	3½	10b
18	3	31	3½	39	0	30	3½	26	3½	22	1½	23	1½	26	2½	45	0	29	0½	29	1	11a
24	2½	30	2½	39	0½	33	0½	27	3½	22	1½	25	0½	27	0½	46	2	29	1½	30	0½	11b
30	0½	33	3½	43	3½	37	3½	34	2½	28	0½	32	1½	34	1½	54	2½	32	1½	35	0½	12a
33	2	32	3½	43	2	37	0½	34	3½	26	2½	33	1½	33	0½	53	1	32	1½	35	0½	12b
29	0	32	1½	42	3	37	0½	34	0½	26	0½	33	1½	31	3½	53	1	31	2½	34	1½	13a
32	2	30	3½	43	2	37	0½	34	3½	27	0½	35	0	32	2½	53	1½	31	3½	34	3½	13b
29	3	35	0½	43	3	37	3½	34	1½	27	1½	33	0½	30	1½	54	1½	31	3½	34	3½	14a
33	1½	34	0½	42	3½	38	1½	34	2½	27	0½	33	3½	32	0½	53	1½	31	3½	35	0½	14b
31	3½	30	0½	42	1½	35	1½	34	0½	25	1½	34	1½	30	1½	48	1½	31	0	33	0½	15a
33	3	32	0	44	1½	37	2	35	0½	28	0	34	3	32	2½	48	0	32	0½	34	3½	15b
33	1½	38	0½	48	3½	41	3	34	8½	32	2	36	1½	36	1½	56	2½	35	0½	38	2	16a
32	2	37	3	50	0	42	0½	34	1½	32	3	37	2	36	0½	55	0½	35	3	38	2	16b
18	3½	31	2½	26	2½	33	1½	21	1½	24	0½	19	1	27	3½	21	0½	27	1½	} 18 3½ } 32 2½	{ 17a 17b 18a 18b	
17	0½	30	1½	25	3½	33	3½	19	3	26	1½	18	0½	27	2½	21	1½	26	3½			
32	3½	17	3½	41	0½	22	3½	32	3½	15	1½	32	1½	18	1½	46	1½	27	2½			
33	1½	18	0	40	0½	20	2½	32	2	16	1½	33	1½	18	2½	46	0½	27	0½			
30	0½	32	1	41	2½	33	1½	30	2	24	0½	32	2	23	1½	46	2½	30	3½	31	2½	19
17	2½	17	0½	19	2½	17	0	17	8½	12	0½	13	0½	12	1½	17	2½	16	1	15	2½	20
24	1½	22	1½	24	0	24	1½	26	1½	15	2	16	1½	20	1½	27	2½	21	3½	22	0½	21
24	2½	21	1½	23	0½	22	0	24	0½	13	3½	19	2½	20	0½	29	3	21	1½	21	2½	22

⁴ The average given for Plots 17 is that of 12 years mineral manure succeeding ammonia-salts (Plots 17 or 18); and that given for Plots 18, of 12 years ammonia-salts succeeding the mineral manure (Plots 17 or 18).

EXPERIMENTS AT ROTHAMSTED ON THE GROWTH OF

APPENDIX.—TABLE XXIII.—WEIGHTS

Plots.	HARVEST.										
	1844. ¹	1845.	1846.	1847.	1848.	1849.	1850.	1851.	1852.	1853.	1854.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
0	58.5	56.5	62.3	61.1	58.4	..	60.8	61.9	55.8	49.8	61.0
1	59.0	54.8	62.6	61.2	59.6	..	..	61.7	56.9	46.9	60.2
2	59.3	56.8	63.0	62.3	58.2	63.8	61.9	63.6	58.2	51.1	62.5
3	58.5	56.5	63.8	61.0	57.3	61.4	60.6	61.1	56.6	45.9	60.6
4	58.0	58.0	63.5	61.9	58.5	63.0	61.2	62.6	57.3	46.6	61.1
5a	58.3	57.5	{ 63.7 63.0 }	61.8	59.2	63.1	60.4	63.3	57.5	48.6	61.0
5b		57.3	{ 63.4 63.3 }	61.4	59.1	63.4	60.4	63.3	57.3	48.6	61.6
6a		57.8	{ 63.7 63.5 }	62.1	58.8	63.0	61.1	63.3	57.6	51.5	61.8
6b	60.0	57.8	63.5	61.6	56.9	63.0	61.3	63.3	57.5	51.5	61.8
7a	60.3	57.0	63.0	61.7	59.4	63.1	61.0	63.0	56.0	52.1	61.9
7b			63.4	61.5	59.6	62.9	61.2	63.0	55.8	51.9	61.8
8a	61.3	56.3	63.5	62.1	56.2	61.7	61.1	62.8	55.9	51.7	61.4
8b			63.6	61.7	59.4	63.0	61.0	62.6	55.9	51.8	61.8
9a	62.3	58.3	63.0	{ 62.5 61.0 }	56.7	62.8	60.4	62.4	55.6	47.4	60.7
9b			63.3	61.3	58.3	62.3	60.8	62.0	55.3	46.9	60.7
10a	62.0	56.3	63.6	61.5	58.1	62.3	60.2	61.9	55.9	48.6	60.5
10b			63.8	61.2	57.8	62.3	61.1	62.5	57.3	49.5	61.6
11a	61.8	56.0	63.3	61.6	59.6	62.6	61.0	62.3	55.6	50.7	61.1
11b			63.2	61.6	57.9	63.0	61.1	62.5	55.9	51.1	61.2
12a	61.5	55.3	63.0	62.0	59.3	64.3	61.5	63.1	57.4	52.0	62.2
12b			63.4	61.8	59.2	64.3	61.4	62.5	57.3	51.9	62.2
13a	62.5	56.3	63.5	62.5	57.9	64.1	60.2	62.6	57.5	52.1	62.2
13b			63.2	62.3	58.4	64.1	61.0	62.3	57.1	51.9	62.2
14a	61.3	57.5	63.0	62.8	58.8	64.3	61.1	62.9	56.9	51.9	62.2
14b			63.4	62.8	58.5	64.3	61.5	62.8	56.7	52.4	62.2
15a	62.0	57.5	62.5	63.0	58.1	64.2	61.5	62.7	57.4	51.6	62.1
15b			63.0	62.6	56.9	64.1	61.0	62.9	56.8	51.7	62.4
16a	62.5	56.3	62.5	62.3	60.0	64.5	60.3	63.5	55.0	52.3	61.7
16b			62.7	62.6	58.4	64.6	60.4	63.4	54.5	52.3	61.7
17a	62.3	55.8	62.8	62.3	59.7	64.3	61.2	63.3	56.5	49.5	62.1
17b			63.0	62.0	59.7	64.4	61.5	63.1	56.9	48.6	62.2
18a	62.0	56.5	62.8	62.7	59.2	64.0	61.2	63.0	57.0	52.6	61.2
18b			62.0	62.9	59.6	64.0	60.9	62.4	56.7	52.6	61.0
19	61.8	57.0	62.0	62.8	56.2	63.9	60.8	62.4	56.1	52.4	61.7
20	..	56.0	..	62.5	58.3	..	59.1	60.8	56.6	47.5	60.8
21	..	..	..	..	..	..	..	61.9	56.9	50.3	61.2
22	..	..	..	..	..	..	..		55.9	49.3	61.0

¹ See foot-note No. 5, to Appendix Table I. p. iii.² For Plots 0, 1, 20, 21, and 22, the averages are for only 19, 18, 17, 13, and 13 years respectively.³ On Plots 17 and 18 the manures have alternated during the last 12 years; that is, ammonia-salts on Plots 17, and the mixed mineral manure on Plots 18, in one year; mineral manure on Plots 17, and ammonia-salts on Plots 18, in the next year, and so on.

WHEAT YEAR AFTER YEAR ON THE SAME LAND.

per BUSHEL of DRESSED CORN, each Year.

HARVEST.									AVERAGE.		Plots.
1855.	1856.	1857.	1858.	1859.	1860.	1861.	1862.	1863.	Of 20 Years, ^a 1844-63.	Of last 12 Years, 1852-63.	
lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
60.7	56.8	59.0	61.2	54.0	53.5	57.6	58.5	62.6	58.4	57.5	0
60.5	56.3	59.0	60.7	55.0	52.8	57.6	58.0	62.3	58.1	57.2	1
62.0	58.6	60.4	62.6	56.5	55.5	60.5	61.0	63.1	60.0	59.3	2
59.2	54.3	58.3	60.4	52.5	52.6	57.4	57.8	62.7	57.9	56.5	3
59.5	55.5	58.8	61.1	55.0	53.0	58.0	58.5	62.3	58.7	57.2	4
59.9	56.5	59.0	61.5	56.0	54.0	59.1	59.0	63.0	59.1	57.9	5a
60.1	56.2	58.8	61.4	56.0	53.1	59.0	59.0	63.0	59.0	57.8	5b
60.3	58.2	59.9	62.1	56.5	53.7	59.5	59.5	62.3	59.6	58.6	6a
60.9	58.5	59.8	62.1	56.5	54.2	59.4	59.8	62.3	59.5	58.7	6b
59.4	58.0	60.5	61.9	55.9	54.3	59.0	59.3	62.6	59.5	58.4	7a
59.5	57.6	60.3	62.3	55.9	54.3	58.9	59.5	62.5	59.4	58.3	7b
58.8	56.8	60.8	61.8	54.0	52.8	58.3	59.2	62.3	58.9	57.8	8a
58.7	57.1	60.6	61.7	53.4	52.3	58.5	59.0	62.3	59.1	57.8	8b
58.3	57.2	60.1	60.8	54.5	51.5	56.8	59.5	62.1	58.4	57.1	9a
57.3	56.3	58.0	58.8	50.5	48.5	53.9	56.3	62.5	57.7	55.4	9b
57.1	55.6	58.0	59.6	51.5	49.5	55.0	56.5	62.6	57.8	55.9	10a
58.9	57.2	58.6	61.4	52.5	51.0	55.5	57.5	62.8	58.6	57.0	10b
55.3	57.3	58.5	60.5	51.4	51.0	55.3	58.0	62.5	58.3	56.4	11a
56.3	57.5	58.0	60.4	51.3	51.2	55.8	58.0	62.1	58.3	56.6	11b
59.5	58.7	60.4	62.1	54.5	53.4	58.1	58.0	62.1	59.4	58.2	12a
60.2	58.8	60.4	62.1	54.8	53.5	58.7	58.0	62.2	59.5	58.3	12b
59.9	58.6	60.6	62.1	55.0	54.3	59.9	58.0	62.6	59.6	58.6	13a
60.4	58.9	60.5	62.7	55.0	53.8	60.0	58.0	62.5	59.7	58.6	13b
60.0	58.6	60.5	62.1	54.5	53.7	59.1	58.0	62.5	59.6	58.3	14a
60.0	59.0	60.3	62.0	54.5	53.2	59.3	58.1	62.5	59.6	58.4	14b
60.0	59.1	60.4	62.6	55.0	53.8	60.0	58.3	62.5	59.7	58.6	15a
60.6	59.4	60.0	62.8	55.0	54.0	60.2	58.3	62.9	59.7	58.7	15b
58.2	58.5	60.5	62.1	52.6	52.0	58.0	58.0	62.4	59.2	57.6	16a
58.2	58.7	60.5	62.1	52.6	51.7	58.6	57.5	62.3	59.1	57.6	16b
60.8	59.0	59.1	62.5	55.0	54.1	59.3	58.1	62.8	59.5	58.0 ^d	{17a 17b 18a 18b}
60.3	59.1	58.8	62.5	54.5	54.3	59.1	58.1	62.8	59.4		
60.9	57.8	59.7	62.3	55.5	54.5	59.6	58.5	62.6	59.7		
60.8	57.7	59.8	62.4	56.0	54.6	59.5	58.5	62.8	59.6		
58.7	58.9	59.5	62.5	55.5	53.0	58.8	57.2	62.9	59.2	58.1	19
61.1	57.7	58.4	60.3	52.5	51.5	57.9	57.3	62.5	57.7	57.0	20
60.8	58.0	60.6	61.5	54.0	52.5	58.2	58.1	62.5	58.2	57.9	21
60.1	57.8	60.6	61.5	55.0	53.8	58.5	58.0	62.4	58.1	57.8	22

^a The average given for Plots 17 is that of 12 years mineral manure succeeding ammonia-salts (Plots 17 or 18); and that given for Plots 18, of 12 years ammonia-salts succeeding the mineral manure (Plots 17 or 18).

EXPERIMENTS AT ROTHAMSTED ON THE GROWTH OF
APPENDIX.—TABLE XXIV.—TOTAL CORN,

Plots.	HARVESTS.										
	1844. ¹	1845.	1846.	1847.	1848.	1849.	1850.	1851.	1852.	1853.	1854.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
0	1228	1967	1906	2031	1259	..	1220	1296	919	599	1672
1	1040	1689	1509	2119	1124	..	..	1251	825	404	1529
2	1276	1967	1826	1981	1705	2068	1861	2049	1716	1120	2675
3	923	1441	1207	1123	952	1229	1002	1083	860	359	1359
4	888	1879	1777	1780	1583	2063	1785	1919	870	446	1521
5a	956	1431	1305	1921	1911	2446	1974	2473	1038	587	1578
5b			1827								
6a	964	1871	1598	2132	1932	2651	2018	2611	1065	611	1532
6b			2076								
7a	984	1682	1400	1663	1672	2410	1960	2271	1288	978	2186
7b			1967								
8a	980	1716	1632	1737	2484	1980	2119	1300	1072	2239	2950
8b			1534								
9a	1280	2131	1682	1963	2531	2112	2532	1643	1357	2944	3065
9b			1549								
10a	1008	1980	1263	1481	1856	1785	1863	1651	1425	3208	2456
10b			1988								
11a	1116	1880	1477	1755	1181	2035	1951	2142	1591	691	2456
11b			1717								
12a	1004	1842	1669	1475	1762	1970	1509	649	2480	2211	2535
12b			1850								
13a	1072	1558	1216	1705	1604	2157	1171	1937	1343	896	2535
13b			1628								
14a	1016	1743	2044	1984	2317	2001	2216	1472	1015	2859	2756
14b			2055								
15a	1096	2103	1641	2149	1940	2163	1387	1073	2756	1283	2966
15b			1661								
16a	1304	2028	1953	2396	1935	2234	1503	1283	2966	1375	2939
16b			1955								
17a	1240	2093	1660	1959	1955	2340	2027	2102	1480	1341	2913
17b			1998								
18a	1368	2048	1801	1730	2346	1964	2083	1476	1396	2858	2946
18b			1605								
19	1580	2114	1812	1856	1726	2123	1995	2121	1530	1347	2863
20	..	1495	2112	2214	1571	2109	1693	1839	1451	1143	2801
21	..	..	1861	2140	1607	2005	1942	2077	1520	1351	2810
22	..	..	1592	1959	1973	2254	2134	2499	1794	1496	3230
	..	..	2019	2283	1948	2268	2159	2501	1700	1537	3293
17a	1240	2093	1592	1959	1973	2254	2134	2499	1794	1496	3230
17b			2019								
18a	1368	2048	2241	2222	1933	2316	1985	2149	1577	520	2948
18b			2034								
19	1580	2114	2048	2160	1734	2163	1934	2083	869	1111	1526
20	..	1495	1474	2029	1804	2243	1845	2090	921	1256	1511
21	..	..	..	..	..	..	..	..	..	..	..
22	..	..	..	..	..	..	..	..	..	..	..

¹ See foot-note No. 5, to Appendix Table I. p. iii.² For Plots 0, 1, 20, 21, and 22, the averages are for only 19, 18, 17, 13, and 13 years respectively.³ On Plots 17 and 18 the manures have alternated during the last 12 years; that is, ammonia-salts on Plots 17, and the mixed mineral manure on Plots 18, in one year; mineral manure on Plots 17, and ammonia-salts on Plots 18, in the next year, and so on.

WHEAT YEAR AFTER YEAR ON THE SAME LAND.

in lbs., per Acre, per Annum.

HARVEST.									AVERAGE.		Plots.
1855.	1856.	1857.	1858.	1859.	1860.	1861.	1862.	1863.	Of 20 Years, 1844-63.	Of last 12 Years, 1852-63.	
lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
1096	1179	1181	1332	1254	826	1001	1228	1429	1296	1143	0
1179	1102	1118	1055	1189	717	828	1024	1334	1169	1025	1
2237	2277	2587	2512	2263	1864	2202	2447	2886	2076	2232	2
1072	892	1236	1141	1051	738	736	996	1127	1026	964	3
1168	1026	1386	1206	1188	832	863	1049	1303	1327	1072	4
1157	1167	1409	1187	1277	903	1047	1119	1283	1422	1146	5a
1143	1247	1512	1227	1273	935	1082	1101	1296	1495	1169	5b
1753	1717	2211	1818	1808	1210	1755	1715	2522	1759	1747	6a
1811	1755	2193	1850	1855	1326	1818	1797	2534	1815	1796	6b
2084	2312	2782	2450	2097	1612	2263	2200	3477	2121	2268	7a
2138	2244	2902	2530	2089	1597	2183	2265	3507	2152	2283	7b
1909	2507	3058	2680	2068	1759	2290	2477	3668	2064	2377	8a
2153	2400	3129	2675	2007	1787	2190	2452	3559	2125	2386	8b
1932	2019	2767	2384	1806	1858	2162	2688	3576	1991	2161	9a
1605	1679	2220	1470	1412	1155	909	1641	2723	1670	1621	9b
1285	1505	1816	1439	1207	905	854	1457	2587	1547	1435	10a
1805	1727	2185	1775	1500	1060	1033	1600	2858	1655	1693	10b
1210	2001	2432	1977	1628	1270	1455	1706	2979	1860	1834	11a
1580	1946	2397	2099	1698	1307	1578	1734	3060	1875	1885	11b
1940	2102	2747	2437	2060	1648	2009	2096	3533	2064	2194	12a
2172	2079	2729	2387	2115	1577	2144	2025	3454	2065	2207	12b
1924	2036	2714	2384	2037	1575	2168	1953	3453	2032	2165	13a
2110	2008	2739	2397	2087	1600	2304	2019	3439	2049	2203	13b
1954	2195	2781	2413	2054	1583	2125	1886	3627	2042	2191	14a
2158	2162	2699	2436	2074	1563	2173	2008	3450	2043	2205	14b
2030	1923	2681	2285	2053	1510	2188	1872	3114	1989	2088	15a
2193	2045	2765	2436	2095	1614	2249	2029	3127	2053	2186	15b
2100	2426	3131	2702	2026	1856	2338	2225	3710	2239	2420	16a
2115	2450	3194	2717	2005	1889	2432	2233	3607	2284	2431	16b
1227	1983	1642	2150	1247	1409	1229	1747	1370	1761	1181 ⁴	17a
1110	1935	1583	2181	1168	1548	1166	1685	1389	1724		17b
2127	1140	2566	1472	1973	929	2050	1168	3006	1774		18a
2170	1131	2519	1338	1980	963	2122	1195	3009	1751		18b
1967	2059	2600	2177	1903	1435	2107	1479	3054	1984	2016	19
1155	1075	1213	1089	1039	722	872	818	1137	1033	989	20
1533	1398	1538	1574	1538	893	1109	1273	1796	1373	1384	21
1553	1351	1491	1412	1460	847	1306	1250	1907	1352	1362	22

^a The average given for Plots 17 is that of 12 years mineral manure succeeding ammonia-salts (Plots 17 or 18); and that given for Plots 18, of 12 years ammonia-salts succeeding the mineral manure (Plots 17 or 18).

EXPERIMENTS AT ROTHAMSTED ON THE GROWTH OF

APPENDIX.—TABLE XXV.—TOTAL STRAW

Plots.	HARVESTS.										
	1844. ¹	1845.	1846.	1847.	1848.	1849.	1850.	1851.	1852.	1853.	1854.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
0	1436	3977	2561	3277	2074	..	2037	1862	1706	1807	2114
1	1203	3699	1953	3735	1735	..	..	1845	1497	1632	2531
2	1476	3915	2454	3628	3041	3029	3245	3094	3457	3372	4450
3	1120	2712	1513	1902	1712	1614	1719	1627	1597	1413	2137
4	1104	3663	2390	2948	2713	2645	3312	2949	1571	1670	2338
5a	1116	2684	1541	3412	3266	3589	4504	4131	1903	1951	2520
5b			2309								
6a	1100	3644	1721	3721	3633	3824	4379	4294	2032	2130	2503
6b			2901								
7a	1172	3243	1676	2786	2878	3072	3927	3624	2581	2777	3845
7b			2571								
8a	1160	3663	2803	2968	3516	3959	3507	2604	2798	4055	5603
8b			1968								
9a	1368	4058	3007	2953	3413	3396	4280	4302	3772	3734	5496
9b			1963								
10a	1112	4266	3683	2317	1815	3407	2769	3806	3966	6135	6117
10b			2575								
11a	1200	4104	2506	2506	1945	2683	3550	3252	3714	2399	4142
11b			3052								
12a	1116	4134	2603	2858	2918	1810	3165	2942	3374	2253	4243
12b			2554								
13a	1204	3355	2244	2891	2367	2851	3089	3070	2787	2049	3597
13b			1455								
14a	1176	3696	2133	3517	3274	2892	3806	3386	3081	2524	5147
14b			2715								
15a	1240	4044	2163	3452	3390	3371	3921	3600	3257	3665	5503
15b			2554								
16a	1480	4191	2327	3306	3290	3236	4026	3544	3222	3704	5398
16b			2755								
17a	1422	3826	2031	3362	3257	3211	4052	3605	3547	3471	5552
17b			2534								
18a	1768	3819	2897	3218	4015	3537	3607	3761	5418	5418	5418
18b			2936								
19	1772	4215	2425	4202	3295	3270	3527	3348	3397	3213	4677
20	..	3104	..	2074	1721	..	1639	1609	1577	1659	2217
21	..	..	..	..	..	..	..	..	..	..	..
22	..	..	..	..	..	..	..	1763	2108	2181	3440
									2179	1860	3340

¹ See foot-note No. 5, to Appendix Table I. p. iii.² For Plots 0, 1, 20, 21, and 22 the averages are for only 19, 18, 17, 13, and 13 years respectively.³ On Plots 17 and 18 the manures have alternated during the last 12 years; that is, ammonia-salts on Plots 17, and the mixed mineral manure on Plots 18, in one year; mineral manure on Plots 17, and ammonia-salts on Plots 18, in the next year, and so on.

WHEAT YEAR AFTER YEAR ON THE SAME LAND.

(and CHAFF), in lbs., per Acre, per Annum.

HARVESTS.									AVERAGE.		Plots.
1855.	1856.	1857.	1858.	1859.	1860.	1861.	1862.	1863.	Of 20 Years, ^a 1844-63.	Of last 12 Years, 1852-63.	
lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
1726	1969	1545	1902	2310	1445	1768	2030	1825	2072	1846	0
1890	1933	1532	1630	2300	1380	1387	1748	1745	1965	1767	1
3845	4317	3323	3837	4810	3440	3101	4195	4279	3515	3869	2
1787	1558	1577	1670	2175	1459	1254	1713	1600	1693	1662	3
1832	1731	1572	1673	2230	1520	1330	1662	1654	2125	1732	4
1819	2012	1617	1532	2323	1580	1493	1840	1687	2345	1856	5a
1800	2122	1735	1643	2393	1660	1610	1860	1768	2501	1938	5b
2837	3050	2757	2577	3747	2183	2573	2839	3714	2909	2957	6a
3037	3093	2757	2713	3853	2393	2683	3100	3716	3044	3067	6b
3911	4560	3680	3965	4677	3003	3501	3906	5853	3776	4187	7a
4156	4398	3891	4092	4803	3137	3555	3913	5878	3830	4236	7b
3839	5182	4297	4667	5353	3880	3913	4723	6715	3862	4706	8a
4342	5089	4450	4667	5597	3813	3795	4635	6489	3977	4725	8b
3946	3875	3867	4317	5270	4777	4445	6050	6312	3739	4426	9a
3212	3152	2983	2688	3590	3130	2170	3256	4197	2998	3187	9b
2512	2818	2392	2130	2790	2213	1930	2593	3481	2656	2608	10a
3268	3168	2875	2615	3420	2360	2163	2843	4056	2866	3061	10b
2484	3517	2943	2797	3527	2503	2577	2842	4233	3124	3181	11a
3153	3443	2920	3018	3577	2693	2645	2873	4459	3176	3285	11b
3538	3847	3647	3663	4550	3230	3192	3649	5443	3617	3932	12a
4010	3725	3583	3673	4743	3087	3337	3609	5365	3607	3962	12b
3503	3743	3707	3693	4737	2993	3318	3589	5739	3582	3945	13a
3870	3651	3647	3677	4807	3037	3490	3672	5799	3632	4033	13b
3577	4202	3658	3737	4763	3053	3377	3397	5459	3609	3983	14a
4003	4117	3652	3710	4700	3103	3303	3550	5299	3615	4019	14b
3825	3521	3687	3515	4773	2877	3318	3396	5162	3499	3795	15a
4222	3752	3778	3698	4993	3090	3478	3758	5113	3669	4028	15b
4534	5529	4683	4797	5927	4117	4423	4527	7007	4441	5152	16a
4991	5467	4703	4813	5793	4207	4343	4497	6725	4511	5151	16b
1976	3558	2058	3203	2483	2700	1753	3080	1918	3060	1985 ⁴ 3755 ⁴	{ 17a 17b 18a 18b }
1804	3465	1940	3274	2373	2970	1663	3077	1903	2988		
4017	2012	3443	2008	4533	1720	3094	1993	4883	3065		
4215	1938	3365	1967	4650	1743	3324	2140	4728	3096		
3851	3562	3193	3185	4023	2743	3238	2653	4523	3416	3521	19
1831	1888	1564	1790	2217	1433	1468	1517	1472	1807	1714	20
2419	2529	1815	2373	3185	1746	1640	2192	2483	2298	2343	21
2457	2498	1807	2180	2980	1567	1957	2180	2692	2266	2308	22

⁴ The average given for Plots 17 is that of 12 years mineral manure succeeding ammonia-salts (Plots 17 or 18); and that given for Plots 18, of 12 years ammonia-salts succeeding the mineral manure (Plots 17 or 18).

EXPERIMENTS AT BOTHERHAMSTED ON THE GROWTH OF

APPENDIX.—TABLE XXVI.—TOTAL PRODUCE

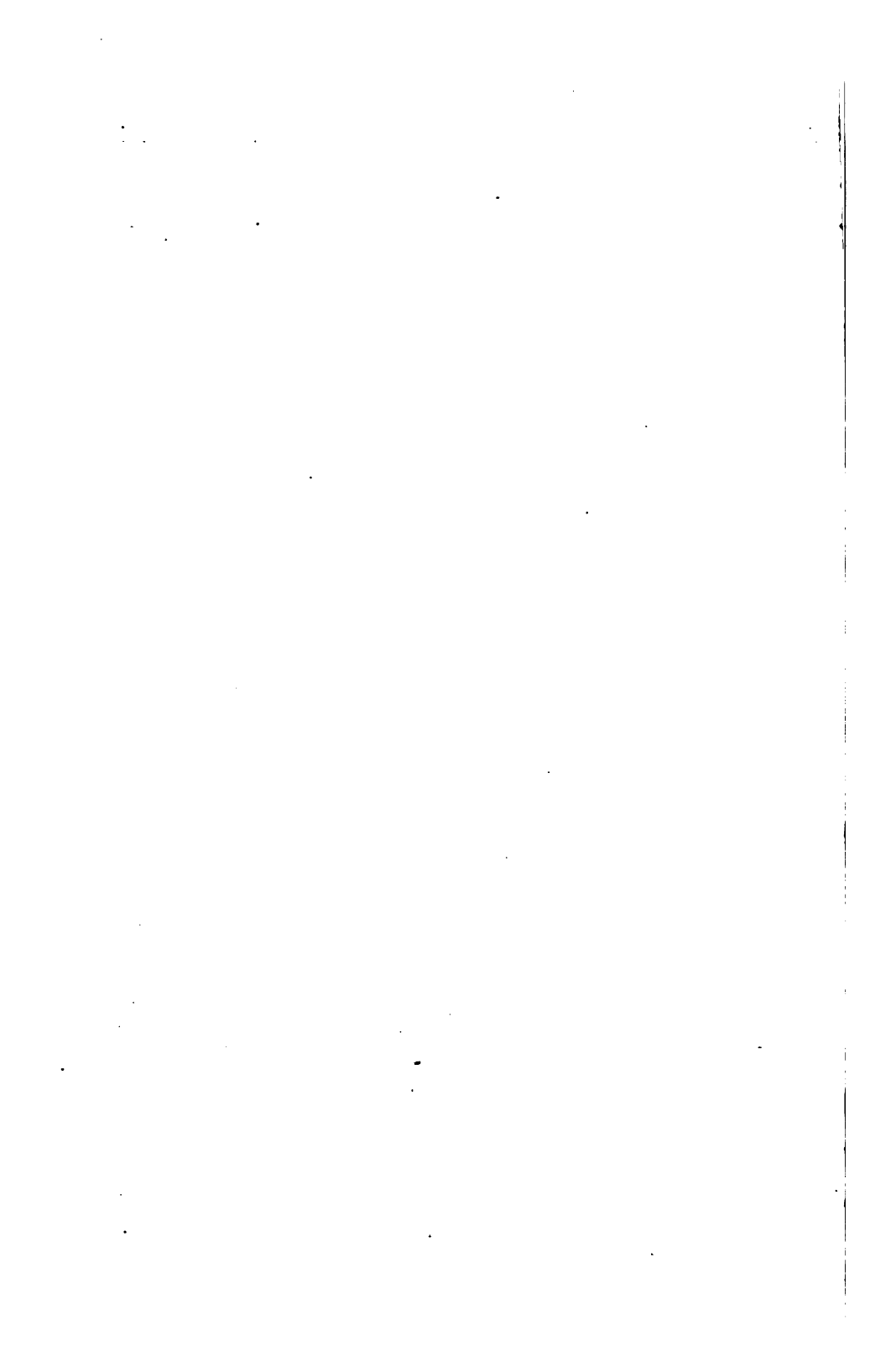
	HARVESTS.										
Plots.	1844. ¹	1845.	1846.	1847.	1848.	1849.	1850.	1851.	1852.	1853.	1854.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
0	2664	5944	4467	5308	3333	..	3257	3158	2625	2406	3786
1	2243	5388	3462	5854	2859	..	..	3096	2322	2036	4060
2	2752	5882	4280	5609	4746	5097	5106	5143	5173	4492	7125
3	2043	4153	2720	3025	2664	2843	2721	2710	2457	1772	3496
4	1992	5542	4167	4728	4296	4708	5097	4868	2441	2116	3859
5a	2072	4115	2846	5333	5177	6035	6478	6604	2941	2538	4098
5b			4136								
6a	2064	5515	3319	5853	5465	6475	6397	6905	3097	2741	4035
6b			4977								
7a	2156	4925	3076	4449	4550	5482	5887	5895	3869	3755	6031
7b			4538								
8a	2140	5379	4435	4502	4705	6000	5939	5626	3904	3870	6294
8b			3502								
9a	2648	6189	5170	4635	5376	5927	6392	6834	5415	5091	8440
9b			4635								
10a	2120	6246	3512	4576	4587	3285	4927	4912	4883	2902	6723
10b			4545								
11a	2316	5984	4094	4593	3701	4992	4810	5036	4107	2691	5808
11b			2671								
12a	2120	5976	4579	4530	5117	3120	4985	4162	3578	7003	7003
12b			3761								
13a	2276	4913	5561	5258	5209	5807	5602	4553	3539	8006	8006
13b			4770								
14a	2192	5439	5439	4539	5091	5681	5465	4299	3780	7776	7776
14b			3824								
15a	2336	6147	4509	4597	5577	5918	5784	4724	5079	8412	8412
15b			3987								
16a	2784	6219	5265	5245	5576	6053	5646	4702	5045	8311	8311
16b			4753								
17a	2662	5919	5265	5245	5576	6053	5646	4702	5045	8311	8311
17b			4753								
18a	2192	5439	5265	5245	5576	6053	5646	4702	5045	8311	8311
18b			4753								
19	3352	6329	4314	6397	5133	5264	5377	5379	4979	4373	7343
20	..	4599	..	3406	2771	..	2507	2565	2452	2084	3662
21	..	..	..	..	..	..	..	2995	3285	2934	5470
22	..	..	..	..	..	..	..	..	3355	2432	5334

WHEAT YEAR AFTER YEAR ON THE SAME LAND.

(CORN and STRAW), in lbs., per Acre, per Annum.

HARVEST.									AVERAGE.		Plots.
1855.	1856.	1857.	1858.	1859.	1860.	1861.	1862.	1863.	Of 20 Years, ^a 1844-63.	Of last 12 Years, 1852-63.	
lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
2822	3148	2726	3234	3564	2271	2769	3258	3,254	3368	2989	0
3069	3035	2650	2685	3489	2097	2215	2772	3,079	3134	2792	1
6082	6594	5910	6349	7073	5304	5303	6642	7,165	5591	6101	2
2859	2450	2813	2811	3226	2197	1990	2709	2,727	2719	2626	3
3000	2757	2958	2879	3418	2352	2193	2711	2,957	3452	2804	4
2976	3179	3026	2719	3600	2483	2540	2959	2,970	3767	3002	5a
2943	3369	3247	2870	3666	2595	2692	2961	3,064	3996	3107	5b
4590	4767	4968	4395	5355	3393	4328	4554	6,236	4668	4704	6a
4848	4848	4950	4563	5708	3719	4501	4897	6,250	4859	4863	6b
5995	6872	6462	6415	6774	4615	5764	6106	9,336	5897	6455	7a
6296	6642	6793	6622	6892	4734	5738	6178	9,385	5982	6519	7b
5747	7689	7355	7347	7421	5639	6203	7200	10,383	5926	7083	8a
6495	7489	7579	7342	7604	5600	5985	7087	10,048	6102	7111	8b
5878	5894	6634	6701	7076	6635	6607	8738	9,888	5730	6587	9a
4817	4831	5203	4158	5002	4285	3079	4897	6,920	4668	4808	9b
3797	4323	4208	3569	3937	3118	2784	4050	6,068	4203	4038	10a
5073	4895	5060	4390	4920	3420	3196	4443	6,914	4521	4754	10b
3694	5518	5375	4774	5155	3773	4032	4548	7,212	4984	5015	11a
4733	5389	5317	5117	5275	4000	4223	4607	7,519	5051	5170	11b
5478	5949	6394	6100	6610	4878	5201	5745	8,976	5681	6126	12a
6182	5804	6312	6060	6858	4664	5481	5634	8,819	5672	6169	12b
5427	5779	6421	6077	6774	4568	5486	5542	9,192	5614	6110	13a
5980	5659	6386	6074	6894	4637	5794	5691	9,238	5681	6236	13b
5531	6397	6439	6150	6817	4636	5502	5283	8,986	5651	6174	14a
6161	6279	6351	6146	6774	4666	5476	5558	8,749	5658	6224	14b
5855	5444	6368	5800	6826	4387	5506	5268	8,276	5488	5883	15a
6415	5797	6543	6134	7088	4704	5727	5787	8,240	5722	6214	15b
6634	7955	7814	7499	7953	5973	6761	6752	10,717	6680	7572	16a
7106	7917	7897	7530	7798	6096	6775	6730	10,332	6795	7582	16b
3203	5541	3700	5353	3730	4109	2982	4827	3,288	4821	3166 ⁴ 5809 ⁴	{17a}
2914	5400	3523	5455	3541	4518	2829	4762	3,292	4712		{17b}
6144	3152	6009	3480	6506	2649	5144	3161	7,889	4839		{18a}
6385	3069	5884	3305	6630	2706	5446	3335	7,737	4847		{18b}
5818	5621	5793	5362	5926	4178	5345	4132	7,577	5400	5537	19
2986	2963	2777	2819	3256	2155	2340	2335	2,609	2840	2703	20
3952	3927	3353	3947	4723	2639	2749	3465	4,279	3671	3727	21
4010	3849	3298	3592	4440	2414	3263	3430	4,599	3618	3670	22

⁴ The average given for Plots 17 is that of 12 years mineral manure succeeding ammonia-salts (Plots 17 or 18); and that given for Plots 18, of 12 years ammonia-salts succeeding the mineral manure (Plots 17 or 18).



ON
THE SELECTION OF
ARTIFICIAL MANURES
FOR THE
SUGAR CANE.
BY J. B. LAWES.

THE effects of sulphate of ammonia upon the growth of the sugar-cane are so striking, and the increase in its use during the last few years has been so great, that it seems desirable that a few words of caution and advice should be offered to those who are in the habit of using that valuable manure. As far back as 1847, when so much distress prevailed in the West Indian Colonies, I drew up a paper, at the request of some gentlemen interested in sugar production, in which I gave it as my opinion that the judicious employment of Artificial Manures for the growth of the cane was likely to prove highly beneficial. I was led to this conclusion, partly by a careful study of the known conditions of growth of the cane and of its treatment for the production of sugar, and partly also by a consideration of the effects of different descriptions of manure on plants botanically allied to the cane. During the fifteen years which have elapsed since the date of the paper just referred to, much experience has been gained, not only in regard to the action of manures on plants allied to the cane, but also as to their action on the growth of the cane itself, grown under such widely different climatic circumstances. The result has been fully to confirm the conclusions before arrived at. I now feel fully justified, therefore, in offering to Planters, with more confidence, some advice on the selection and application of Artificial Manures.

The sugar-cane belongs to the Gramineous family of plants, which furnishes food to a large proportion of the inhabitants of

the globe. Thus, wheat, barley, oats, rye, maize, rice, the sugar-cane, and the grasses of our meadows and pastures, are all members of the great natural order—Graminaceæ. Although flourishing under very different conditions of soil and climate, these allied plants possess many characteristics in common. Their stems contain a large quantity of siliceous matter; the juice of the unripe plant is generally highly saccharine; and the ripened seeds abound in starch. The food products for which they are cultivated are principally, though not exclusively, sugar and starch, substances which are closely allied to one another in chemical composition; whilst each can be formed from the other, either artificially or under the influence of the processes of vegetation. Further, so far as experience supplies information on the point, various members of the Gramineous family, though cultivated under very different conditions in different parts of the world, have, in the main, been found to give increased growth, and increased yield of their valuable food products, under the influence of similar descriptions of manure.

It is especially the case that those manures which, whether used experimentally, or under the ordinary circumstances of cultivation in this country, have been found to be the most effective in increasing the produce of the graminaceous grains, wheat, barley, and oats, and of the grasses of our meadows, have also had the greatest effect on the increased growth of the cane, and on the yield of sugar over a given area of land. I shall, therefore, by way of illustration, here quote some of the results obtained in experiments on the application of different manures to the wheat crop, so far as they have a bearing upon the question now under consideration.

In the autumn of 1843, now nearly twenty years ago, a field of about 14 acres, on my farm at Rothamsted, was set apart for experiments on the growth of wheat with different descriptions of manure year after year on the same land. A crop of wheat has been taken from this field every year since, and the experiments are still in progress. More than twenty different combinations of manuring substances are used each year, the

same description being, for the most part, applied year after year on the same plot of land.

It is obvious that results obtained over a long series of years in the manner here described, must give a tolerably correct indication as to which constituents the soonest became deficient, and which, therefore, it was the most necessary to supply to the land in order to maintain or increase the growth of wheat under the circumstances in question, when the crop was grown year after year on the same land, and the entire produce was removed without the usual periodical supply of farm-yard manure.

One portion of the land was always left unmanured; one manured with alkali-salts alone; one with superphosphate of lime alone; one with alkali-salts and superphosphate of lime together; one with ammonia-salts alone; one with ammonia-salts and superphosphate of lime; one with ammonia-salts, superphosphate of lime, and alkali-salts together, and so on; and, finally, one plot was manured with farm-yard manure, at the rate of 14 tons per acre each year.

The following Table shows the weight of the total produce (corn and straw together), and of the total increase, obtained per acre during the last ten years, under the influence of each of the conditions of manuring above enumerated:—

		Corn and Straw per acre, in ten years, 1852-1861.	
		Produce.	Increase.
		Cwts.	Cwts.
1	Unmanured, continuously.....	232	.....
2	Alkali-salts, alone	246	14
3	Superphosphate of lime, alone.....	262	30
4	Superphosphate and alkali-salts, together.....	274	42
5	Ammonia-salts, alone	342	110
6	Ammonia-salts and superphosphate of lime	438	206
7	Ammonia-salts, superphosphate, and alkali-salt together.....	556	324
8	Farm-yard manure, 14 tons per acre per annum	530	298

It is seen that the mineral manures used alone (Nos. 2, 3, and 4,) gave but very little increase over the produce of the unmanured land, the amount obtained per acre in ten years being only 14 cwts. by alkali-salts alone; 30 cwts. by superphosphate of lime alone; and 42 cwts. by superphosphate of lime and alkali-salts together.

The increase in experiments 5, 6, and 7, where ammonia-salts were employed, was very much greater; but very much the greater when the ammonia-salts were used in combination with mineral manures, than when they were used alone. Thus, the increase of produce in ten years by ammonia-salts alone was 110 cwts.; by the same amount of ammonia-salts mixed with superphosphate of lime it was nearly twice as much, or 206 cwts.; and by the same amount of ammonia-salts mixed with both superphosphate of lime and alkali-salts the increase was 324 cwts., or nearly three times as much as by the ammonia-salts alone. Lastly, it is especially worthy of remark, that the latter amount of increase, obtained by the combination of salts of ammonia, superphosphate of lime, and alkali-salts, was considerably greater than by a liberal dressing of farm-yard manure.

The result was, then, that mineral manures used alone gave very little increase; that ammonia-salts used alone gave very much more than mineral manures alone; that a combination of both ammonia-salts and mineral manures gave very much more increase still, in fact, more even than farm-yard manure.

The amount of farm-yard manure employed supplied, each year, more, both of combustible carbonaceous substance, and of mineral matter, than was taken off in the crop. On the other hand, the mixtures of ammonia-salts and mineral manure contained no carbonaceous substance whatever. Notwithstanding this, one of these mixtures, No. 7, gave, as has been seen, more increase than the farm-yard manure with its large supply of such substance. The fact is, there is no doubt, that the wheat plants obtained nearly the whole of their vegetable substance, either by their roots or their leaves as the case may be

from the atmosphere; but that the amount they stored up depended very much upon the supply of ammonia and mineral constituents provided within the soil.

Assuming that the habits and requirements of growth of the sugar-cane are closely allied to those of wheat in regard to the points above referred to, it follows that nitrogenous manures, such as sulphate of ammonia, will considerably increase its growth, and with it the produce of sugar from a given area of land, and that ammonia-salts in combination with mineral manures will do so in a still greater degree.

Sugar is an organic substance composed of carbon, hydrogen, and oxygen, constituents which are derived from the atmosphere and water. Hence, if nothing were taken from the land but pure sugar, there would be no loss of mineral constituents from the soil. But it happens in practice, that nearly the whole of the constituents of the cane are lost to the soil. Thus, little or none of the nitrogenous, or ammonia-yielding substance, contained in the produced cane, is returned to the land. A large proportion of the alkali-salts, or more soluble mineral matters is extracted in the juice and remains chiefly in the molasses, and partly intermixed with the impure sugar. Lastly, the expressed cane, which is burnt as fuel, contains the remainder of the nitrogenous substance, which is destroyed and lost in the combustion; it also contains nearly one-third of the soluble, and nearly the whole of the more insoluble portions of the mineral constituents, which remain in the stoke-hole ashes, and are but seldom returned to the land.

It is obvious, therefore, that in the growth and manufacture of sugar as at present practised, there is, besides vegetable matter, a great loss of the mineral constituents of the soil, which will, of course, be the greater when the amount of produce is increased by means of ammonia-salts alone. To show the nature of this loss more in detail, it may be mentioned that fresh cane, as taken from the land, is estimated to contain about 0.45 per cent. of mineral matter; and assuming this to be the case, every 10 tons of cane taken from an acre of land will remove from it about 100 lbs. of mineral matter, which, according

to the average of twelve analyses of cane-ash by Dr. Stenhouse, will contain the following constituents :—

	Ash constituents in 10 tons fresh cane.
	lbs.
Silica	43·2
Phosphoric Acid.....	6·8
Sulphuric Acid	6·6
Lime	8·4
Magnesia	7·6
Potass.....	16·6
Chloride of Potassium	4·9
Soda	0·5
Chloride of Sodium	5·4
	100·0

As already said, perhaps about two-thirds, or more, of the more soluble of the above mineral matters, will be contained in the expressed juice, and if the whole of the sugar and molasses obtained from it were sold, the whole of this portion would be lost to the land; but the saline matters of that portion of the molasses which is consumed on the estate, either as food or in the manufacture of rum, should sooner or later find their way back to the land in the form of manure. The stoke-hole ashes, the residue of the combustion of the expressed cane, and containing the remaining mineral constituents, including the greater part of the phosphoric acid, the lime, the magnesia, the silica, and the remaining amount of the salts of potass and soda, should also find their way back to the land. But, from the hard, glassy, and insoluble condition of these ashes, they will be of little or no use as manure unless finely ground before they are applied, and even then their action will be but slow.

Under any circumstances, therefore, a considerable proportion of the mineral matter of the produced cane must be lost to the land; the portion that is returned can be but very imperfectly distributed throughout the soil; and so much of it as is applied in the form of stoke-hole ashes, including the phosphates, will be in a comparatively insoluble condition. Soluble phosphate is, however, extensively manufactured in England for the purposes of

manure, and can be supplied at a very cheap rate. Potass, another constituent of which the land is considerably drained in the production of sugar, is much more expensive, and fortunately exists in most soils in much larger proportion to the amount required than does phosphoric acid. It is extremely desirable that at any rate both phosphoric acid and potass should enter into the composition of the artificial manures used for the sugar-cane; and more especially so when ammonia-salts are employed. In this way, not only will the ammonia, or nitrogen, the most expensive constituent of manures, be greatly economised, but the exhaustion of the soil which must inevitably follow the use of ammonia-salts alone, will be prevented.

As the roots of the cane extend to a considerable depth, it may take some years before the exhaustion and injury arising from the exclusive use of ammonia-salts will become manifest—but sooner or later the drain of the mineral matters will show itself. The first symptom will be a diminished result from the application of the ammonia-salt; and the manufacturers or importers of this valuable manure will be accused of furnishing an adulterated article. But it would be still more damaging to the interests of the planter himself, that he should wait until the evil consequences have developed themselves. The artificial manures, by means of which the restoration must be made, can only be distributed through the soil to the depth of a few inches; and it is only in the course of years, that any appreciable amount of their valuable constituents can reach the lower layers; so that, when injurious results have once been produced, they will not admit of a speedy remedy.

As a manufacturer of manures, it is, in a pecuniary sense, of little importance to me whether I sell sulphate of ammonia alone or in combination with other substances; but I feel by no means indifferent as to the success attending the use of the manures I supply. Within the last few years considerable advance has been made in the knowledge of all that relates to the application and action of manures; and it would be a subject of much regret were the owners of colonial property to suffer, in addition to their other difficulties, from diminished produce and depreciation of land, arising from the want of a

due apprehension and application of those principles, by the aid of which some other branches of agriculture have of late years so much profited.

It is, of course, optional with those interested in the production of sugar to make the alterations I have to suggest, or not, as they may think best. I propose, however, to manufacture a special manure for the sugar cane to be called cane-manure, of which the greater proportion will be sulphate of ammonia, and the remainder will consist of such a combination of mineral constituents as is the most suitable for the cane, taking into consideration the character and circumstances of growth of the crop, and the mode of dealing with the produce. I may add that I do not anticipate very sudden or striking results to be observable on the use of this manure instead of sulphate of ammonia alone; but I have, at the same time, the fullest confidence that the ultimate result will be beneficial.

The most important conclusions for the planter to bear in mind may be briefly enumerated as follows:—

1. That the constituents of sugar, and of nearly the whole of the combustible portions of the cane, are derived from the air and water, and not from the soil itself.

2. That ammonia used as manure most strikingly increases the growth of the cane, provided the soil be not deficient in mineral constituents.

3. That large quantities of mineral constituents are taken from the land in the cane crop, part of which find their way into the molasses and the impure sugar, and the remainder are contained in the ashes left on burning the cane refuse as fuel.

4. That the mineral constituents of the molasses consumed on the plantation, and the stoke-hole ashes (after being finely ground) should be returned to the land as manure.

5. That there is an inevitable loss to the soil of some of the mineral constituents taken from the land in the cane, and hence it is necessary to provide such constituents in the artificial manures used for the crop.

1, ADELAIDE PLACE, LONDON BRIDGE,

January, 1863.

ON THE
ACCUMULATION OF THE NITROGEN OF
MANURE IN THE SOIL.

BY

J. B. LAWES, F.R.S., F.C.S., and J. H. GILBERT, Ph.D., F.R.S., F.C.S.

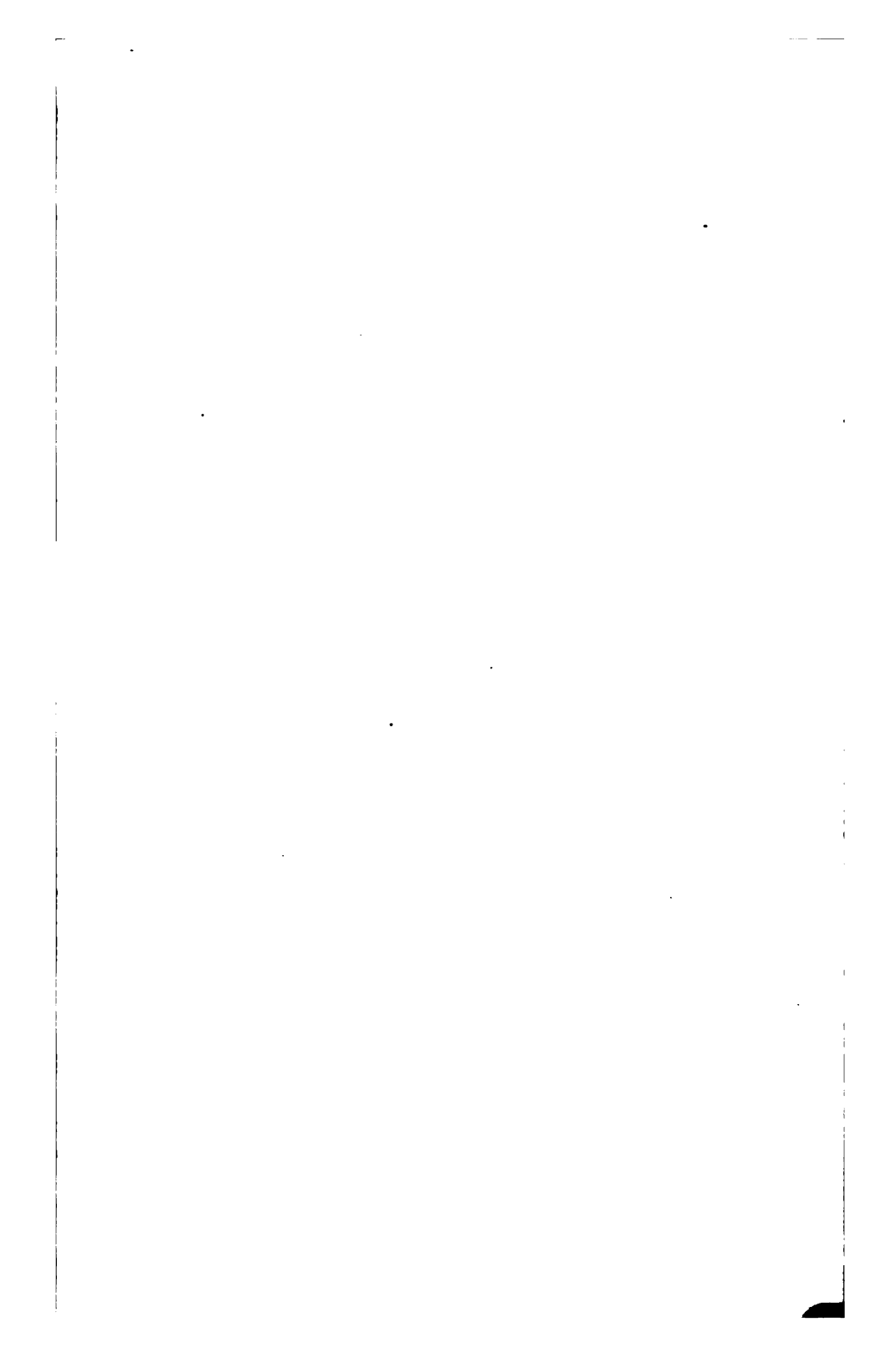
THE authors had been engaged for many years in an investigation in the course of which they had grown wheat year after year on the same land for more than twenty years; on some portions without any manure, and on others with farm-yard manure, or with various descriptions of manure. They had published the results obtained in the field during the first twenty years of the experiments*; and they had been for some time, and were still, engaged in investigating the composition of the produce grown under the different conditions, and also the comparative composition of the soils of the different plots, as affected by the various treatment.

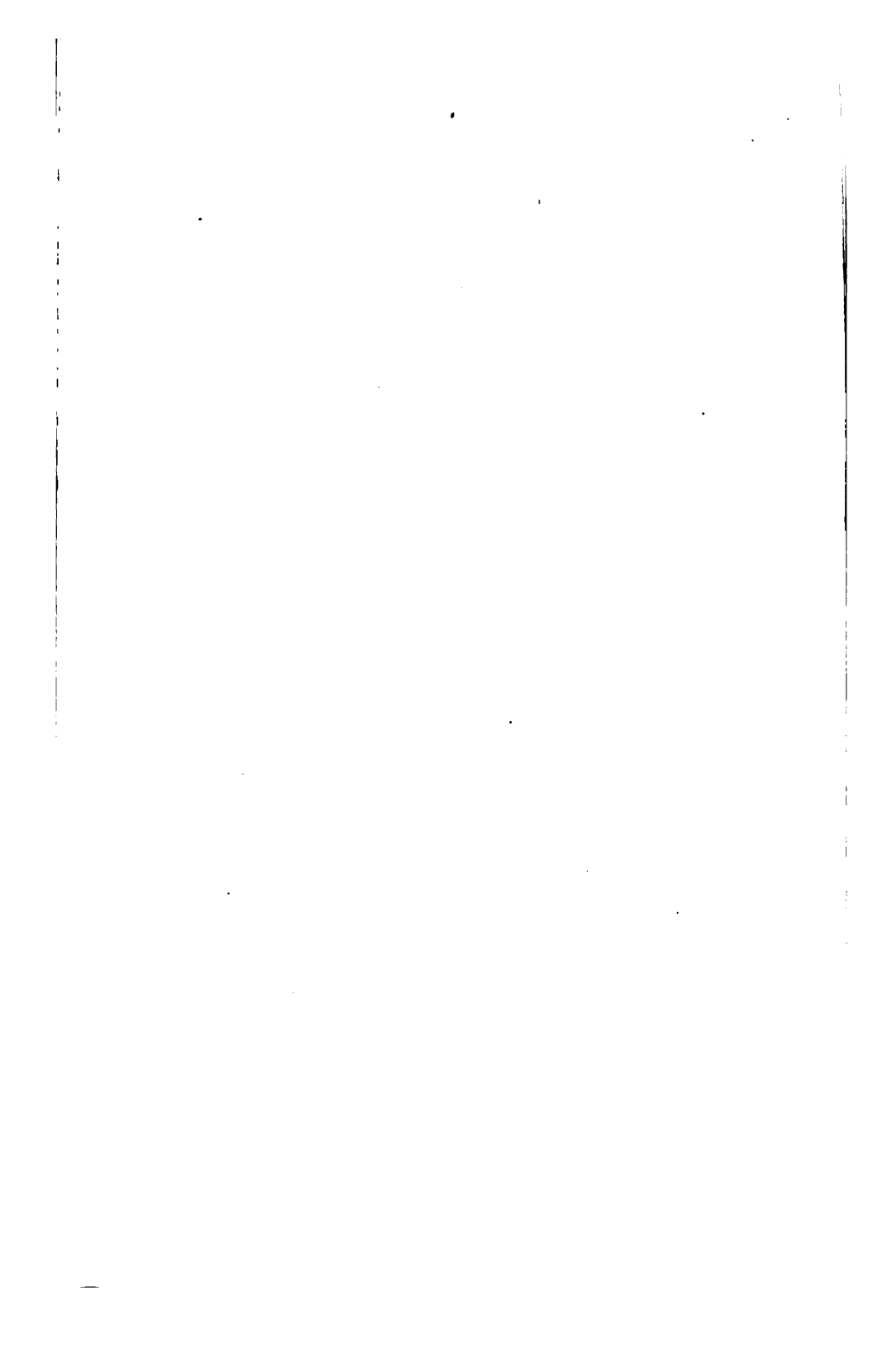
The point to which they chiefly confined attention on the present occasion was, the accumulation, and the loss, of the nitrogen which had been supplied in the manure and not recovered in the increase of crop. After discussing the difficulties of sampling, preparing for analysis, and analyzing soils in such manner as to yield results applicable to the purposes of their inquiry, and describing the methods they had adopted, they called attention to some of the results obtained, summaries of which were brought to view in Tables hung up in the room. The percentage, and calculated acreage, amounts of nitrogen existing in such condition as to be determinable by burning with soda-lime were given for the soil, of the first, of the second, and of the third nine inches, of eleven differently manured plots, showing the amounts, therefore, to the depth of 27 inches in all.

The accumulation of nitrogen from the residue of manuring was found to be, in some cases, very considerable; but even with equal amounts supplied, it varied, both in total amount and in distribution, according to circumstances, the depth to which the unused supply had penetrated, being apparently influenced by the character and amount of the associated manurial constituents. The general result was, that, although a considerable amount of the nitrogen supplied in manure which had not been recovered as increase of crop was shown to remain in the soil, still a larger amount was as yet unaccounted for. Initiative results indicated that some existed as nitric acid in the soil, but it was believed that the amount so existing would prove to be but small. In fact, it was concluded that a considerably larger proportion would remain entirely unaccounted for within the soil to the depth under examination than was there traceable, and the probability was, that at any rate some of this had passed off into the drains, and some into the lower strata of the soil. Finally, it was shown, by reference to field results, that there was not more than one or two bushels of increase in the wheat crop per acre per annum, due to the large accumulated residue of nitrogen in the soil, notwithstanding its amount was many times greater than that which would yield an increase of twenty bushels or more, if applied afresh to soil otherwise in the same condition. On the other hand, it was shown that the effect of an accumulated residue of certain mineral constituents was not only very considerable in degree, but very lasting.

* "Report of Experiments on the Growth of Wheat for Twenty Years in succession on the same Land," Journ. Roy. Ag. Soc. Eng. vol. xxv. pts. 1 & 2.







PRELIMINARY NOTICE

OF

RESULTS ON THE COMPOSITION OF WHEAT

GROWN FOR TWENTY YEARS IN SUCCESSION

ON THE SAME LAND.

BY

J. B. LAWES, F.R.S., F.C.S., AND J. H. GILBERT, PH.D., F.R.S., F.C.S.

THESE results had reference to the produce of a field in which wheat had now been grown, on some plots without manure, on one with farmyard manure, and on others by different artificial mixtures, for twenty-four years in succession (1843-4 to 1866-7 inclusive). At the Cheltenham Meeting of the British Association in 1856, the authors treated of the effects of season and manures on the composition of the crop as illustrated by the results of analysis relating to the produce of some of the plots during the first ten years of the experiments.¹ At the Manchester Meeting, in 1861, they recurred to the subject; the analytical results, which then extended to the produce of some of the plots for sixteen years, were, however, chiefly applied to the illustration of certain points in connexion with the exhaustion of soils. At the Nottingham Meeting, in 1866, they treated of the accumulation of the nitrogen of manure in the soil of the same experimental field. The results adduced on the present occasion showed the effects of season and manuring on the composition of both the grain and the straw during twenty years of the experimental growth.

The particulars of composition given are—the percentages of dry substance, of mineral matter, and of nitrogen, and the constituents of the ash of both grain and straw, more than 200 complete ash-analyses being brought to bear on the subject; and, side by side with these, as indicating the general characters of the

¹ "On some points in the Composition of Wheat-grain, its products in the Mill, and Bread." *Journ. Chem. Soc.* vol. x.

produce of the different seasons and plots, are given the proportion of grain to straw, and the weight per bushel of the grain.

In the case of the plots without manure, with farmyard manure, and with ammonia-salts alone, every year, the ash of the grain of the last sixteen, or more, and of the straw of the last sixteen, of the twenty years, had been analysed; and in the case of nine differently manured plots (including the above three), the ash, of both grain and straw, of the first, the last, and two intermediate seasons (one bad and one good) of the last twelve of the twenty years had been analysed. It was the intention of the authors to publish the results of the investigation in detail before long; and on the present occasion they confined attention to a few of the most prominent effects of the respective manures on the composition of the crop, when thus applied for so long a continuance, year after year, on the same plot.

It is first pointed out as remarkable, though fully established by their results from the commencement, that variation in manure, even though maintained for many years in succession, and resulting in great variation in amount of produce, affects comparatively little either the proportion of grain to straw, or the weight per bushel of the grain; excepting, indeed, in a few extreme cases of abnormal exhaustion or repletion. Nor do the percentages of dry substance, of mineral matter in dry substance, or of nitrogen in dry substance, vary much under the direct influence of variation in manure, unless again in very abnormal cases. Very different, however, is the effect of season; the variation in the character of the produce, in every one of the above particulars, being much greater in different seasons with the same manure, than with different manures in the same season.

Consistently with these broad facts, the composition of the ash of the grain is found to be pretty uniform under a great variety of manurial conditions in one and the same season; only in a few extreme cases, of special interest, varying in any material degree. The same may be said in some, though in a much less degree, of the composition of the ash of the straw, which is obviously much more directly affected by the character of the supplies within the soil.

The general result is that (excepting in a few abnormal cases) the variation in the composition of the ash of the grain is limited to the slight variations due to differences of development and maturation, which, in their turn, are much greater with variation of season than with variation of manure. The composition of the ash of the straw, on the other hand, much more nearly represents the total mineral matters taken up by the plant, and much less the character of development of its own more fixed and essential constituents. In other words, whilst there may be considerable range in the composition of the matters taken up by the entire plant, the tendency in the formation and ripening of the ultimate product, the seed (whether produced in small quantities or large), is to a fixed and uniform composition, the deviation from which is little directly affected by the character of the supplies within the soil, but much more by the various influences of season.

The deviations from the point of fixed and uniform composition, thus due primarily to variations in climatic circumstance, are, however, when considered in relation to other characters of the grain, sufficient to show the general connexion between the comparative predominance of individual constituents and that of certain general characters of development. A few illustrations were given, but the fuller treatment of the subject, in its bearing on these as well as on other points, was reserved until the results could be considered in the detail necessary to their proper elucidation.

One point of interest prominently brought out by the results relating to the composition of the straw-ash was, that a high percentage of silica was almost uniformly associated with a bad, and a low percentage with a good condition of the produce; a fact to which the authors had on former occasions called attention, but which, as was remarked by the President, was quite inconsistent with the generally accepted views on the subject.

ON THE
HOME PRODUCE, IMPORTS,
AND
CONSUMPTION OF WHEAT.

BY
J. B. LAWES, F.R.S., F.C.S.:
AND
J. H. GILBERT, PH.D., F.R.S., F.C.S.

LONDON:
LONGMANS, GREEN, READER. AND DYER
PATERNOSTER ROW.

1868.

FROM THE
JOURNAL OF THE ROYAL AGRICULTURAL SOCIETY OF ENGLAND,
VOL. VI.—S.S., PART II.

London : Printed by WILLIAM CLOWES and SONS, Duke Street, Stamford Street,
and Charing Cross.

ON THE

HOME PRODUCE, IMPORTS, AND CONSUMPTION OF WHEAT.

It is almost a truism to say that the characters of the seasons exert a very great influence on the amount and quality of our home-produce of wheat from year to year; and that upon the amount of food which the crop supplies depends very materially, though less than formerly, the general prosperity of the nation. In a very able paper by Mr. Caird,* devoted in great measure to pointing out the important bearings of the Agricultural Returns for 1866 and 1867, which were presented to Parliament last year,† he estimates the cost of the wheat and wheat-flour consumed in the United Kingdom at 30,000,000*l.* sterling more for the year, in consequence of the bad season of 1867, than after the good harvest of 1863; and that, out of this total extra cost, 27,400,000*l.* more would have to be paid for foreign corn after the bad harvest than after the good one. He calls attention to the influence which such a result must have upon the trade of the country, and insists upon the great advantages which would accrue from early knowledge as to the area and yield of our various crops.

Hitherto the objections of farmers, whether valid or otherwise, have been sufficient to prevent the legislature from requiring returns to be made on these and other points comprised under the head of 'Agricultural Statistics.' In Ireland for a number of years past, and in Scotland also for a few seasons some years ago, returns have, however, been collected. But it is only during the last two years that voluntary returns have been collected throughout the United Kingdom, as to the number of acres under each crop, and some other points; and in regard to the important question of the amount of produce obtained, either per acre or in the aggregate, no returns whatever have been collected; nor is any really reliable information available on the subject.

To meet this want, the managers of some of our best conducted agricultural papers have, however, bestowed much care and trouble in collecting, just before harvest, from correspondents

* Read before the Statistical Society, March 17, 1868; and afterwards published as a pamphlet under the title of 'Our Daily Food; its Price, and Sources of Supply.' Longmans & Co.

† Agricultural Returns for Great Britain, with Abstract Returns for the United Kingdom, 1867.

residing in various parts of the United Kingdom, opinions as to the probable yield of the various growing crops. But as these returns are, for the most part, made before the crops are fully ripe, they sometimes require considerable correction afterwards, either in consequence of changes in the weather before the produce is secured, or when the results of the thrashing-machine are known. Then, again, the terms "average," "over average," and "under average," which are chiefly used in describing the crops, are but vague and indefinite. They are, nevertheless, preferable to those which are much more definite, when applied to crops not even harvested. The returns so collected are, however, not only the best at our command, but they are extremely valuable.

As will be known to many agricultural readers, wheat has been grown in a 14-acre field at Rothamsted, for twenty-five years in succession; the field being divided into plots, some of which are unmanured, one receiving farmyard manure every year, and the rest receiving, each a different description or amount of artificial manure; the same description and amount of manure having been applied to the same plot each year, for the last seventeen years. In all other respects the management is the same over all the plots each year, and, as far as possible, the same year after year. The result is, that the difference in the quantity and quality of the produce from year to year is mainly due to the varying characters of the seasons. Most of the plots are 6-10ths of an acre each, but some are only 3-10ths.

After careful observation and comparison, for a series of years, of the fluctuations of result obtained in the experimental wheat-field from year to year, and of those in the crop of the country generally, it was thought that the results of certain selected plots would afford an useful indication of the general character of the wheat-crop of the country. Accordingly, for the last six years, as soon as the crop was thrashed, a statement of the produce obtained on those plots, together with such comments as seemed appropriate, has been sent to '*The Times*' for the information of those interested in the subject. Referring to the results in that field, Mr. Caird, in the paper above quoted, says that they "have proved a very satisfactory index of the general yield over the chief wheat-producing area of the kingdom, and are indeed the most instructive series of facts for the guidance of the British corn-grower on record."

However valuable and instructive the records in question may be, in default of more directly applicable information, it will, nevertheless, be seen further on, how very requisite is more exact knowledge than can possibly be acquired by such means, to enable us to form really reliable estimates of the total, or even of the acreage, yield of wheat in the country at large. At the

same time, the collecting together and attempting to apply such data as we do possess, will of itself be instructive; and it is hoped that the course of the inquiry will at least bring to view some useful and important facts in regard to the *home-produce*, the *foreign supply*, and the *consumption* of *wheat*—undoubtedly the most important staple food of the population of the United Kingdom.

For various reasons it will be convenient to confine the illustrations to the period commencing with the harvest of 1852 and ending with that of 1868. Thus, so far as the results in the experimental wheat-field supply data for the calculations, the season of 1851-2 is the first that could be brought under consideration; since, before that date, there was not the perfect uniformity in the description and amount of artificial manures used year after year on one and the same plot as there has been from that date to the present time. Again, not much before that time had producers and importers thoroughly made up their minds as to the influence on their relative positions of the changes brought about by the establishment of free trade in corn a few years previously; nor, perhaps, had the effects of that great change on the consumption of wheat been much earlier thoroughly established. The year of 1851, indeed, terminated a period of lower prices of wheat than have since prevailed. In the week ending October 11th, 1850, the *Gazette* price of wheat was 35*s.* 6*d.*; in January, 1854, under the combined influence of a previous bad harvest and of war, it reached as high as 83*s.* 3*d.*; and, during the past summer, the price has been twice as high as in the first year of the period selected for our review. In the three successive *harvest-years* (Sept. 1—Aug. 31) 1860-1, 1861-2, and 1862-3, there were imported into the United Kingdom from 9,000,000 to 10,000,000 quarters of wheat annually; or, in the first of the three, more than, and in the other two nearly, as much as, would supply the total flour and bread consumed by one-half of the then existing population. In 1854-5 and in 1855-6, on the other hand, the imports were only sufficient for the requirements of about 17 per cent. of the population. We have also had within the period, in 1853 probably the worst harvest since 1816, and in 1863 the most productive since 1834.

Since 1852 the population of the United Kingdom has increased by about 3,000,000 = about 11 per cent.; and, independently of this great increase in the actual number of the consumers of flour and bread, it is pretty certain that the amount consumed per head of the population has also increased: in Great Britain, perhaps, more directly as the result of Free Trade in corn and the relaxation of many other restrictions on trade and commerce; but in Ireland in a greater degree than in either

of the other main divisions of the kingdom, as one of the results of the much-lessened yield of the potato-crop.

Before attempting to apply the results in the experimental wheat-field as a means of estimating the home-produce of wheat from year to year, and the consequent dependence of the population on home and foreign supplies respectively, it will be well to show how far the fluctuations in the experimental crop, according to season, have accorded in general character and direction with those in the crop of the country at large, so far as these are ascertainable by reference to the published opinions of various authorities, at the time or afterwards.

With a view to such a comparison, and at the same time to provide for reference, in a very summary form, an useful record of the wheat-producing characteristics of the different seasons, there are given in the annexed Table (I.), some of the results obtained on certain selected plots in the experimental wheat-field; and, side by side with these are given in the notes, after much more detailed compilation in the first instance, and as correctly as possible consistently with the necessary brevity, the substance of the opinions of the various authorities quoted. The plots selected are those the results of which have been published in '*The Times*' shortly after harvest for some years past, as already referred to, namely:—

Plot 3. Permanently unmanured.

Plot 2. Having 14 tons of farmyard manure each year.

Plots 7, 8, and 9. Manured respectively with different artificial mixtures, the same being applied to the same plot each year; the mean result of the three plots being taken to represent the produce by artificial manure.

The mean result, each year, of these three widely-different and characteristic conditions—without manure, with farmyard manure, and with artificial manure—is taken to represent the average produce for the year. The particulars given are—the actual bushels per acre; the bushels per acre reckoned at the uniform weight of 61 lbs. per bushel; the weight per bushel; and the proportion of corn to 100 of straw.

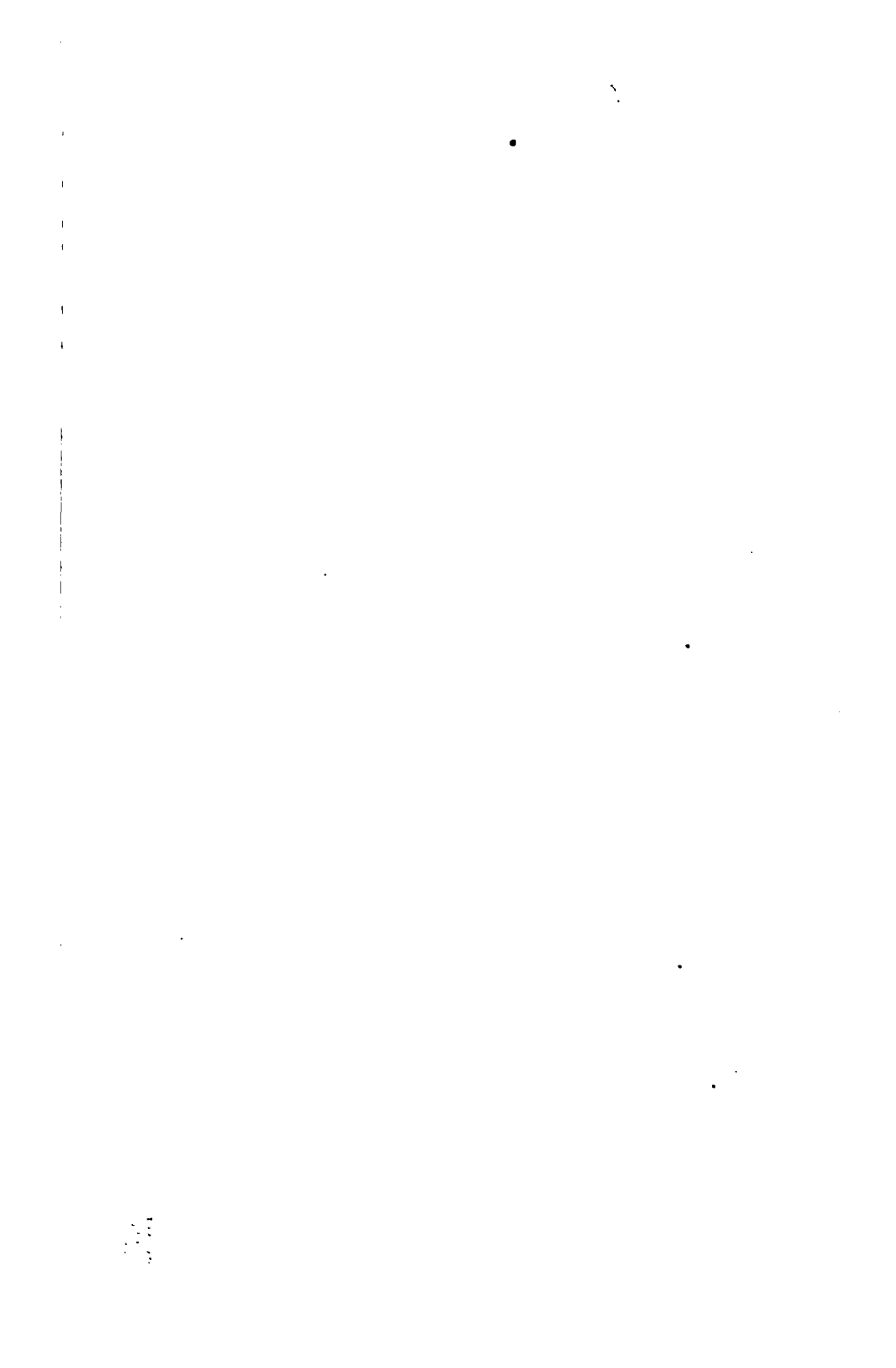
We shall refer in some detail, further on, to the question of the probable average yield of wheat per acre in the three main divisions of the United Kingdom; but we may here observe in passing, that Mr. Caird * estimates the average yield in England at the present time to be 28 bushels. The coincidence with this figure of the results obtained on the selected plots in the experimental field, as recorded in the Table, is sufficiently remarkable. Thus, if we take the column of *actual* bushels per acre, we have, taking the average of the 16 years, 1852-67,

* '*Our Daily Food*,' &c., p. 12.

TESTED EXPERIMENTAL FIELD.

Mean of Plot Summary of the published Opinions of various Authorities on

YEAR.	US AUTHORITIES.
	<p>ette. "M. L."—<i>Mark Lane Express</i>. "F. M."—<i>Farmer's Magazine</i>. (4). "L."—<i>J. B. Lawes (Letters to The Times)</i>.</p>
1852	<p>a. good promise but ripened prematurely, harvest unfavourable and tedious; little ning, damp harvest, yield reduced, quality much damaged, foreign needed for mixing; ill bulk, but much blighted, mildewed, and grown; considerably below average.</p>
1853	<p>below average. M. L.—Area very small, unpromising, crop very short and inferior harvest late, total $\frac{1}{2}$ below average; bad crop in France; last crop, and potatoes help; L. & G.—Bad seed time, much reduced area, crop worse than for many years past.</p>
1854	<p>usually productive, best since 1844. M. L.—Land favourable, area very large, over yield very large and very fine; imports limited, but much Indian corn; work slack, ed time, variable season, late harvest, but largest crop for many years past.</p>
1855	<p>id well, crop nearly average. F. M.—Still larger area, promised well, harvest slow, y moderate, scarcity abroad, prices high, consumption reduced; potatoes abundant. ery various.</p>
1856	<p>n quantity but not quality, yield various, red better than white, much early thrashed. ondition; large imports from both Baltic and America; demand for the Continent.</p>
1857	<p>ield. F. M.—Full, or over average area, fine promise throughout, harvest 3 weeks ed, imports generally large, stocks heavy throughout, harvest 1858 early, and much</p>
1858	<p>nise, favourable harvest, fair quantity, good quality, stocks large at harvest 1858, and and light, about average quantity, more than 1855 or 1856, and quality better, straw fine; very early, good harvest; crops above average, though by no means equal 1857.</p>
1859	<p>icient, low weight, much old at harvest 1859; Dec., 130 average, 112 under, 15 over an 1858, very much straw; imports only moderate; towards harvest 1860 not much crops much injured; considerable bulk, but yield below average and quality inferior.</p>
1860	<p>ed well, and much damaged since. M. L.—Full average area, backward in spring, don very bad, mixture required for grinding; imports large throughout, yet small is large, but new will be required early. L. & G.—Unusually wet, stormy, and</p>
1861	<p>area, early condition poor, yield deficient, quality good. F. M.—Deficient area; winter lity good; imports large from America and Baltic, prices declined; at harvest 1862 n good quality.</p>
1862	<p>usually large area in England, Scotland, and Ireland; progress promising, then grind with home; harvest 1863 three weeks early; 1862 crops nearly exhausted;</p>
1863	<p>e. M. L.—Less area than last, good promise throughout, enormous produce, fine crop known, quality seldom equalled; imports generally only moderate, and foreign —Much above average, both quantity and quality; best yield for many years.</p>
1864	<p>last. M. L.—Average area, fair promise, quality fine, stocks very large. F. M.— more than expected, quality fine; imports small, much of 1863 still left, stocks large. —Good soils much above, poor below average quantity; quality above average.</p>
1865	<p>acre = 4 below average, only good clays over average. M. L.—Came up well, good y middling condition. F. M.—Early progress generally favourable, quantity fair much old left, new soon in market; early imports moderate, stock in France large; erage quantity, quality moderate.</p>
1866	<p>rably below 1865, much damaged, but good yield. SAUNDERSON (<i>Times</i>).—Slow y harvest, fair quantity, when new required mixture. F. M.—Early promise good. e. Dec. to Feb., little from America, foreign accumulating, home early reduced, <i>Times</i>, Oct. 10).—Quantity 10 to 12 per cent. deficient, quality above average.</p>
1867	<p>nd quality. <i>Roll's Messenger</i>.—Yield very deficient, quality inferior. AGRICULTURIST ling quality; (Sept.)—Universally admitted to be very deficient. F. M.—Winter fair condition, very little old left, prices high; large arrivals, much will be want- ed old left.</p>
1868	<p>good wheat soils; 126 over, 13 under, 67 average. SAUNDERSON (<i>Times</i>, Aug. 13).— y, and condition, probably never equalled on good soils; shallow soils disappointing. A, yield $\frac{1}{4}$ over 1867. L. (<i>Times</i>, Aug. 17).—Area over average, quantity probably</p>
Aver. 16 yrs., 1852-67.	
Aver. 17 yrs., 1852-68	



28 $\frac{1}{2}$ bushels; or if we take the average of 17 years (that is, including the high produce of 1868) 29 $\frac{1}{2}$ bushels. If, on the other hand, we take the column showing the number of bushels per acre of 61 lbs. per bushel, the correspondence is still closer. Thus, taking the average of the 16 years, we have 28 $\frac{1}{2}$ bushels; or, taking the average of the 17 years (including 1868), 28 $\frac{1}{2}$ bushels.

It is also remarkable that although the variation in the weight per bushel from year to year has been so great as in several cases to show a difference of from 10 to 20 per cent. between the actual number of bushels measured and the number if reckoned at 61 lbs. per bushel, yet, taking the average of the 16 or the 17 years, there is a difference of little more than half a bushel, whether the actual measure, or the measure reckoned at 61 lbs. per bushel, be adopted. It need hardly be said that the measure reckoning 61 lbs. per bushel is by far the better indication both of actual and of relative quantity.

A comparison of the figures in the Table with the briefly-summarised statements from various sources given opposite to them also shows a very general accordance. Thus, 1863, 1854, and 1857 are shown to have been the most productive in the experimental field, and they are admitted by general consent to have been years of very great abundance in the country at large. 1853, 1860, and 1867, on the other hand, gave very deficient crops in the experimental field, and are generally admitted to have been years of great deficiency throughout the country. The figures show the harvest of 1853 to have been not only extremely bad, but the worst on our list; and it is spoken of as having yielded the shortest crop within the generation—indeed, the worst since 1816. Owing to the wet condition of the land, much that had been intended for wheat was not sown with it at all; and much land throughout the country, as was the case in experimental field, was not sown until the spring. Still we do not for a moment assume that the crop of 1853 was, in the country generally, at all relatively so deficient as was our own spring-sown and, in every respect, very exceptionally bad crop.

Again, 1855 is spoken of as scarcely average, and 1856 as about the same, or perhaps rather better, and the experimental field indicated (at 61 lbs. per bushel), between 27 and 28 bushels in both cases: rather more, however, in 1856, if reckoned in *actual* bushels measure. A correspondent in '*The Times*' estimated the crop of 1855 at 8 bushels per acre less than that of 1854, and this is very nearly the difference indicated by the figures in the Table.

In regard to the harvests of 1862 and 1864, the agreement between the results in the experimental field and the yield of the country according to the recorded opinions, is less marked.

It is probable that, in the country generally, the yield per acre in 1862 was not more than average, whereas in the experimental field it proved on thrashing to be rather over average. The area under wheat was, however, stated to be unusually large. The imports were also large, and the harvest of 1863 was two to three weeks earlier than usual, and hence the deficient yield per acre in 1862 was comparatively little felt, and little influenced prices.

The crop of 1864, again, was more above the average in the experimental field than, according to the records, in the country generally. But the wheat crop of that year was, relatively, very much better on the heavier than on the lighter soils. It, moreover, followed the enormous crop of 1863, and was very short in the straw; both of which circumstances would be likely to lead to an under-estimate of its amount. Indeed, it was afterwards spoken of as having yielded better than had been expected. The surplus of 1863 no doubt materially influenced prices during the harvest-year 1864-5; yet, considering the circumstances above-mentioned, the comparatively small amount of the imports, and the very low price, it is very probable that the crop of 1864 was in reality considerably better than the published reports represented it to be, and perhaps but little less above the average than was the crop in the experimental field.

Leaving out of consideration for the present the question of the degree of correspondence in the actual amount per acre, it is obvious that there has, in point of fact, been a very general accordance between the fluctuations in the amount of produce from year to year on the selected plots of the experimental field and those in the produce of the country generally in the corresponding seasons. The coincidence is, to say the least, very marked, and much greater than could have been anticipated.

SOURCES AND CHARACTER OF THE DATA AVAILABLE.

We will now attempt to apply such data as are at command, to estimate the amount of the home-produce, the foreign supplies, and the consumption of wheat, in England and Wales, in Scotland, and in Ireland, each separately; also in Great Britain, and in the United Kingdom collectively, during the 16 harvest-years 1852-3 to 1867-8 inclusive. It will be necessary, however, first to consider, in some detail, the sources and character of the data available for the purpose; in order that a judgment may be formed of how far the conclusions indicated are really reliable, and how far the course of the inquiry serves to show on what points more comprehensive and exact information is essential before really trustworthy estimates can be made in reference to the questions proposed, involving as they do, considerations of such great national interest and importance.

The subjects to be considered are—the extent of area under wheat; the average yield per acre; the aggregate home-produce, and the amount of it available as human food; the quantities imported; the number of consumers; the consumption per head of the population; also some other points.

1. *Area under Wheat.*

On this very fundamental element of the inquiry the information at command is extremely incomplete. Perhaps the average number of acres under wheat, over a series of years, may be estimated for each of the main divisions of the United Kingdom with approximate accuracy. But a consideration of such records as are available, showing the fluctuations in area from year to year, indicated how desirable it was, if possible, to estimate the variation from the average area each year. This, therefore, was attempted with regard to England, which comprises so large a proportion of the total wheat-growing area of the United Kingdom. After much consideration, however, it was decided that the uncertainty, or deviation from the truth, in regard to the area in individual years, might be equally great, and the average result over a series of years perhaps less to be relied upon, if it were attempted to estimate the area for each individual year, and for each separate division of the kingdom, in an arbitrary manner, on the authority of mere opinions or general statements.

After this explanation of the difficulties which beset the question, and at the same time freely admitting the great need of more complete and reliable data on the point, we may here state generally, that, throughout the calculations, we have estimated the area for the years preceding, intermediate to, or succeeding those for which returns or reliable estimates are available, by the simpler method of either adopting those returns or estimates for the proximate years, or distributing the difference between the figure adopted at one date and that at another, equally from year to year.

For neither England nor Wales have we any official records or estimates, of the area under wheat for any year within the period of our review prior to 1866. We have, however, for England Mr. Caird's estimate for 1850. This, so far as we are aware, is the most reliable information available relating to the period prior to the recent official returns. The approximate accuracy of the estimate is, moreover, rendered the more probable from the fact that it gives a somewhat higher acreage than the recent returns; the general opinion being that the area under wheat has diminished during the last 15 or 20 years.

10 *Home Produce, Imports, and Consumption of Wheat.*

The whole of our numerical records in regard to the area under wheat in England are, then, as follows:—

	Acres.
For 1850—Mr. Caird's Estimate	3,416,000
„ 1866—“Agricultural Returns”	3,126,431
„ 1867—Do. do.	3,140,025

Adopting these figures as a basis, we have distributed the difference between the amount estimated for 1850 and that returned for 1866 equally from year to year among the intermediate years.

For Wales the “Agricultural Returns” give us the area for 1866 as 113,862, and for 1867 as 116,733 acres; but we have no information whatever in respect to any other year. We adopt, therefore, the official figure given for 1866 for each of the preceding years.

In Appendix-Table I., p. 36, will be found the estimated area under wheat in England and Wales collectively each year, obtained by the simple addition of the figures adopted for each, as above described.

In regard to Scotland, we have returns of the acreage under wheat in 1854, 1855, 1856, and 1857, collected by the Highland Society*; and for 1866 and 1867, we have the “Agricultural Returns,” collected by officers of the Inland Revenue Service, under the auspices of the Statistical Department of the Board of Trade. The results are as follows:—

TABLE II.—AREA UNDER WHEAT IN SCOTLAND.

Years.	Acres.	AUTHORITY.
1854	168,216	} Highland Society.
1855	191,301	
1856	263,328	
1857	223,153	
Mean ..	211,500	
1866	110,101	} Inland Revenue Officers.
1867	111,118	
Mean ..	110,610	

* ‘Agricultural Statistics of Scotland.’ Reports by the Highland and Agricultural Society of Scotland, to the Board of Trade; 1854, 1855, 1856, and 1857.

It is generally admitted that, of late years, the breadth under wheat in Scotland has considerably diminished, and that under barley and oats increased. But, according to the figures in the Table, we have within the period of the four consecutive years for which returns are given by the Highland Society, a variation in the proportion of about two to three; and taking the mean of the four years 1854, 1855, 1856, and 1857, we have 211,500 acres, against a mean of only 110,610 as returned for 1866 and 1867 by the Inland Revenue Department. Here, then, is indicated a reduction of the area under wheat in Scotland by nearly one-half between the two periods, separated by an interval of only eight years.

Such wide differences with actual returns seem to leave us in as great uncertainty as when we have to rely upon carefully-considered occasional estimates merely. It is possible that part at least of the deficiency of area returned by the Highland Society, in the first two years of their record, may be due to defective machinery of collection in the earlier years of their inquiry; and it is, perhaps, more than probable, that the returns for 1866 and 1867 are lower than they should be, on account of the suspicion entertained by the occupiers, of the object of returns collected by the officers of the Inland Revenue Department. Such, however, are the best data at command relating to the area under wheat in Scotland.

For each of the two years prior to the date to which the Highland Society's first return refers, we have, for want of any recorded information on the subject, taken the mean of their four yearly returns; and for the years intermediate between the two sets of returns, we have distributed the difference between the mean of the results collected by the Highland Society and the mean of the more recent returns by the Inland Revenue officers, equally from year to year. The figures so obtained will be found in the proper column in Appendix-Table II., p. 37.

We have for Ireland a return of the number of acres under wheat, in each individual year to which our inquiry relates.* The figures are given in Appendix-Table IV., p. 39. It will be well, however, briefly to call attention here to the wide range of fluctuation of area under the crop during the 16 years, 1852-1867, which these figures relating to Ireland indicate. The following statement brings to view the most striking points:—

First Year	..	..	..	1852	..	353,566 acres.
Last Year	..	..	..	1867	..	261,034 „
Maximum Area	..	..	..	1857	..	559,646 „
Minimum Area	..	..	..	1863	..	260,311 „
Mean, 16 Years	..	..	..	1852—1867	..	389,084 „

* 'Agricultural Statistics, Ireland.' 1868.

Thus, the area in the first year, 1852, was less than the mean area of the sixteen years ; but it was one-third more than in the last year, 1867. The maximum area was in 1857, and it was more than double the minimum, which was in 1863, only six years later.

The fluctuation of area under wheat in Ireland, during the last 16 years, has, therefore, according to the returns, been very great indeed ; and it has doubtless, in reality, been very considerable. The general result indicated is, a marked increase of area from 1852 to 1856, and a pretty uniform and very large area in 1856, 1857, and 1858 ; then a marked diminution to the minimum point in 1863, and from that time to the present comparatively little change. One element in the explanation of these changes doubtless is, that, during the earlier years, the increase of area was encouraged by a more than average yield per acre. The yield was then only about average during the years of very large area, and it then fell gradually to a very low point in 1862. After this the yield per acre again improved, but the area has not in a corresponding degree been enlarged.

For the Isle of Man, and the Channel Islands, the "Agricultural Returns" give us the area under wheat in 1866 and 1867. But the area and the population of these islands constitute but a fraction of 1 per cent. of the area and population respectively, of the United Kingdom. Nor does the Registrar-General in his estimates of the population of the United Kingdom include the population either of these or of the other islands in the British Seas. Upon the whole we considered it of very questionable utility to take either the area or the consumption of these islands into consideration, and we have therefore disregarded them in the calculations.

We have now described the sources and character of the data at command for the purpose, and adopted returns, or estimates, as the case may be, of the area under wheat, in England and Wales, in Scotland, and in Ireland, in each year from 1852 to 1867 inclusive. The area for Great Britain, and for the United Kingdom, can obviously be estimated by simple addition of the proper items so determined. Accordingly, in Appendix-Table III., p. 38, for Great Britain, and in Appendix-Table V., p. 40, for the United Kingdom, the results of such calculations are given.

2. *Yield of Wheat per Acre.*

It will be obvious that a knowledge of the average yield of wheat per acre, from year to year, is as important an element in estimating the home-produce of the country as is that of the

number of acres under the crop. Yet, it must be admitted that there is as great a deficiency of authentic data in regard to this point as to that of area. The only returns we possess are for Scotland in 1854, 1855, 1856, and 1857, and for Ireland in regard to each individual year included within the period of our inquiry. For England and Wales, which, taking the average of a series of years, probably comprise more than 85 per cent. of the total area under wheat in the United Kingdom, there are no returns whatever.

The average produce of wheat per acre is estimated by various authorities at amounts chiefly ranging from 28 to 32 bushels; some, however, go below 28, and others higher than 32. Perhaps the most generally assumed average is 30 bushels. As already referred to, in 1850 Mr. Caird* estimated the average yield per acre in England at not more than $26\frac{1}{2}$ bushels; and he concludes that, at the present time, it does not exceed 28 bushels. We have ourselves always doubted the trustworthiness of the more sanguine estimates.

Granting then, that, for England and Wales, comprising about $8\frac{1}{2}$ tenths of the whole wheat-growing area of the country, we have no official data whatever upon which to found an estimate of the yield per acre from year to year, the question arises—How are we to attempt to form such an estimate?

It is freely admitted that the character of the data we have to fall back upon is, *à priori*, anything but satisfactory. Nevertheless, it is believed that, in the absence of actual records on the point, the most reliable estimates available may, with proper care and reservation, be founded on the amounts of produce per acre obtained from year to year on certain selected plots (as already referred to) in the experimental field at Rothamsted, in which wheat has now been grown for 25 years in succession; on some plots with the same condition as to manuring from year to year during the whole of that period, and on others for the last 17 years.

It has already been shown that the fluctuations in the average results obtained on the selected plots from year to year, have, in the main, remarkably corresponded in general character and direction with the fluctuations in the yield of the crop over the country generally. But in attempting to get an actual figure to represent the average produce of the country each year, it is obviously essential carefully to consider the characteristics of each harvest, both in the experimental wheat-field and over the country generally; and, accordingly, if it should seem desirable, to subject the actual experimental results obtained to modification

* 'Our Daily Food,' &c., p. 12.

or correction, before adopting them as measures of the average yield of the country.

There is sufficient evidence that the wheat grown at Rothamsted pretty generally weighs less per bushel than the average of the home-grown wheats sent to the English markets. This is more especially the case with the grain from the field devoted to the growth of wheat year after year; and the deficiency is generally the greater the less favourable the season, and the less the actual weight per bushel. This, so far as the *non*-experimental fields, and the heavily artificially manured plots in the experimental field, are concerned, is, doubtless, partly accounted for by the greater bulk of these crops than that of the average in the country.

Considering these circumstances, and the fact already referred to, which will be further illustrated presently, that a given number of bushels per acre may represent very different amounts or weights of produce, and consequently of flour or bread, according to the weight per bushel of the grain, it was obviously desirable to reduce the actual number of bushels per acre to bushels of a given weight. In the construction of the official returns of the imports and exports of wheat and wheat-flour, the quantities entered in cwts. are reduced to quarters by calculations based on the assumption that foreign wheat averages a little under 61 lbs. per bushel measure. On the other hand, the average weight of home-grown wheat, over a series of years, is probably a little over 61 lbs. per bushel.

The first modification to which the actual results obtained in the experimental field are subjected, before adopting their indications as a measure of the yield in the country generally, is, therefore, to reduce the produce per acre into bushels of the uniform weight of 61 lbs.

Again, as the soil in the experimental field is a somewhat heavy loam, with a subsoil of clay, and chalk below, and is of fair average, though not high wheat growing capability, it is obviously a question whether in the seasons most favourable to the heavier soils, the results may not be rather more favourable than those over the country at large, including the shallower, lighter, and poorer soils. In reference to this point, it is, of course, to be borne in mind not only that it is in such seasons that the better wheat soils will have the advantage, but also that it is upon the yield of these that the average much depends.

The season in which, owing to the circumstances above alluded to, the average yield per acre on the selected plots in the experimental field might, if in any, be supposed to be in excess of the average of the country generally, is 1864, as already referred to.

But, as then explained, it is considered pretty certain if there were any excess at all, that it was by no means so great as might be judged by comparison of the amount with the accounts given of the crop about and immediately after harvest. It has been decided, therefore, not to alter the figure which the experimental results indicate for the average yield per acre in 1864; and even should the estimate be somewhat too high, any small error in that direction will probably be more or less compensated in the calculation of the aggregate produce, inasmuch as the area was said to be over average, whereas in the calculations it has been taken at the average only.

On the other hand, there are two years in reference to which there could not be any doubt that the produce in the experimental field was, even for the seasons, exceptionally bad. These are 1852 and 1853, to the latter of which reference has already been made. For these two years, therefore, we disregard the results in the experimental wheat field altogether, and arrive at an estimate of their average yield per acre as follows:—According to Mr. Caird, the general average of the country, irrespectively of fluctuations due to season, would be about 27 bushels at the dates in question; and, after a careful consideration of the published statements respecting the crops, it is assumed that in 1852 the yield per acre was one-sixth, and in 1853 one-fourth below the average of the period.

With these two exceptions, then, and after reducing in all cases the actual number of bushels to bushels of the uniform weight of 61 lbs., we adopt the results on the selected plots in the experimental field as representing, as nearly as any existing data enables us to estimate it, the average yield of wheat per acre in England and Wales, in each of the sixteen years, 1852-1867 inclusive. The results will be found in the proper column in Appendix-Table I. p. 36.

It will be admitted to be a confirmation of the approximate correctness of the estimates thus arrived at, that, taking the average of the results given for each of the 16 years, we get an average for the whole period of $28\frac{1}{2}$ bushels as the yield per acre; whilst Mr. Caird's estimate of $26\frac{1}{2}$ bushels for 1850 and 28 bushels at the present time, would give us an average of about $27\frac{1}{2}$ bushels per acre per annum for the whole period. When, moreover, it is borne in mind that we have had during the period perhaps more than an average of favourable seasons, the agreement between the two estimates comes to be nearer than at first sight appears. It may be further mentioned that if, instead of adopting the mean produce on the selected experimental plots each year modified as above explained, we take as a basis Mr. Caird's estimates of average yield in 1850

and at the present time, and modify the result from year to year, for variations of season, according to the fluctuations over or under the average on the experimental plots, we get, over the 16 years, an average of about $28\frac{1}{2}$ bushels.

For Scotland we have, as already noticed, returns of the number of acres under wheat in 1854, 1855, 1856, and 1857; and having also returns of the aggregate produce of wheat in each of those years, it is obvious that from these data the yield per acre each year can easily be calculated. The figures so obtained are—

										Bushels per Acre.
1854	..	..	..	..	..	..	..	..	..	28 $\frac{1}{2}$
1855	..	..	..	..	..	..	..	..	..	26 $\frac{1}{2}$
1856	..	..	..	..	..	..	..	..	..	27 $\frac{1}{2}$
1857	..	..	..	..	..	..	..	..	..	27 $\frac{1}{2}$
Mean										27 $\frac{1}{2}$

The fluctuations from year to year here indicated are certainly very small. The average for the four years is nearly 4 bushels less than that of the estimates adopted for England and Wales for the same period; but it is only about 1 bushel less than the average for England and Wales over the 16 years. As this is the case, as we have no records whatever to guide us in reference to any of the other years, and as according to the estimates the average area under wheat in Scotland amounts to less than one-twentieth of the total in the United Kingdom, and to not much more than one-twentieth of that in England and Wales, we adopt, for each of the years for which we have no records the same figure for the average yield of wheat per acre in Scotland as in England and Wales. This, it is true, as the above comparison of the results for the 4 years is sufficient to show, may lead to inconsistencies in individual years. Nevertheless, the method of estimate adopted is the best available; and the figure obtained for the average of the whole period will, probably, be not far from the truth; though, perhaps, slightly too high.

For Ireland we have, for each of the 16 years, 1852-1867, returns of the area, and estimates of the aggregate produce; and from these data the average yield of wheat per acre each year has been calculated. The results are entered in Appendix-Table IV., p. 39.

Below is given the average result over the 16 years for each of the main divisions of the United Kingdom separately, and for the whole collectively. The figures for Great Britain, and for the United Kingdom, are not the mere arithmetical means of those given for each of the separate portions, but they are the calculated averages, having regard to the area under the crop in each separate division:—

RETURNED OR ESTIMATED AVERAGE YIELD OF WHEAT per acre per annum
over 16 years, 1852-1867.

	Busbels.
England and Wales	28½
Scotland	27½
Great Britain	28½
Ireland	23½
United Kingdom	28½

Whatever objections may be raised to the method of estimate adopted, or to the results arrived at, in regard to the subject of average yield of wheat per acre, so far as individual years are concerned, it is nevertheless believed that the figures given above represent the truth as closely as existing information enables us to approach it. Assuming the approximate accuracy of the figures, it is to be observed that England and Wales, comprising about 85 per cent. of the whole area, also give a higher average yield per acre than Scotland, which comprises only about 5 per cent.; and Scotland, in its turn, gives a higher yield than Ireland, comprising about 10 per cent. of the whole area. Indeed, owing to the relatively small area under wheat in Scotland, and in Ireland, the average yield per acre for the United Kingdom is comparatively little below that for England and Wales.

3. *Aggregate Home-produce, and the Amount of it available as Human Food.*

For England and Wales the total home-produce is ascertained by multiplying the adopted number of acres under the crop each year, by the estimated number of bushels (of 61 lbs.) per acre, and then reducing into quarters.

For Scotland the same method of calculation is adopted as for England and Wales, excepting for the four years 1854-57, for which the returns of the Highland Society give the aggregate produce in bushels. These have simply been reduced to quarters, regardless of weight per bushel, which, however, from the columns showing the weight per bushel in each of the very numerous districts, would appear to be on the average notably below 61 lbs.

In the case of Ireland, the "*Agricultural Statistics*" give estimates of the aggregate produce each year in quarters, and we adopt the figures as they stand. They also give estimates, by weight, of the average yield per acre; but it is obvious, on dividing the aggregate produce by the recorded number of acres, and comparing the result with that obtained by dividing the recorded average yield per acre by 61, that the measure is given at a considerably lower weight per bushel than 61 lbs.; lower indeed,

than that for Scotland; and doubtless, with the moist climate of Ireland the weight per bushel does in reality average less than in Scotland, and less still than in England and Wales.

Considering the comparatively small proportion of the area under wheat in Scotland and in Ireland to that in the United Kingdom collectively, there will be but an immaterial amount of error due to taking the measure of the aggregate home-produce of those divisions of the kingdom at a lower weight per bushel than 61 lbs.

It will be obvious that the total home-produce, however accurately estimated, does not correctly represent the amount of home-grown wheat available for consumption as flour and bread. A certain amount is each year returned to the land as seed. In estimating the amount of home-grown wheat available for consumption, therefore, we have deducted $2\frac{1}{2}$ bushels per acre from the estimated total produce. Doubtless less than this is devoted to seed, over a large proportion of the area sown in the United Kingdom; but where drill husbandry is not adopted, the quantity will be more. It will probably be so, more especially in the greater part of Ireland, some portions of Scotland, and in some of the northern counties of England. Considering, however, that the quantity will average less over a large proportion of the chief wheat-growing districts of England, the estimate of $2\frac{1}{2}$ bushels will probably not be far from the truth.

4. *Imports.*

For the whole period to which our inquiry relates, we have returns either of the net imports of wheat and wheat-flour, or of the imports and exports, from which the net imports can be calculated, for the United Kingdom collectively, and for Ireland* separately. To get the net imports, that is, the imports less exports, for Great Britain, we have obviously only to deduct those for Ireland from those of the United Kingdom.

Unfortunately, although we are thus able to determine from the beginning the net imports into Great Britain, there are no returns for England and Wales, or for Scotland separately, prior to 1862. From that date, however, we have returns of both imports and exports for England and Wales; and from 1865 returns of imports into Scotland. From 1862 to 1865 we have determined the imports for Scotland by deducting those for England and Wales from those for Great Britain; and, since that date, the returns for Scotland are adopted; and these deducted from those for Great Britain, give the results for England and

* Excepting for 1854, for which we have not been able to procure the returns; and we have therefore adopted for that year the mean of the figures given for 1853 and 1855 respectively.

Wales. There is some immaterial discrepancy between the results so obtained and the actual returns for England and Wales, but the plan was adopted to prevent inconsistency with the figures given for Great Britain.

For the ten years preceding 1862, the date of the first separate returns for England and Wales, we are obliged to rely entirely upon our own judgment in the apportionment of the aggregate imports into Great Britain, to England and Wales, and to Scotland, respectively. We have done it as follows:—For the six years commencing 1862, for which we have the separate returns for England and Wales, or Scotland, or both, the average total amount available for consumption per head per annum in Scotland has been calculated, and it is assumed to have been the same in each of the preceding ten years. This figure is multiplied into the number of the population for each year, giving the estimated aggregate consumption, and from this the returned or estimated amount of home-produce is deducted, and the remainder is the quantity which, it is assumed, has been provided by the net imports. The amount of net imports into Scotland each year being so determined, this deducted from the returned amount for Great Britain gives the estimated quantity of net imports into England and Wales for each of the ten years in question.

In all cases, however, the imports are calculated, not for the calendar, but for the harvest-years; that is, from September 1st of one year to August 31st of the next. In the case of the returns for the United Kingdom for the whole period, and of those for England and Wales and Scotland during the last few years, this has been done by the aid of the records for the individual weeks or months. But so far as Ireland is concerned, we have only had access to returns for each separate calendar year; and, in its case, therefore, the imports for the harvest years have been calculated by adding one-third of the imports of one year to two-thirds of those of the next. For example—for the harvest-year 1852-3 (Sept. 1st, 1852—Aug. 31st, 1853), one-third of the recorded imports for 1852, and two-thirds of those for 1853, taken together, are assumed to represent the imports of that harvest-year, and so on.

Exceptional deviations from the above methods of record or estimate are explained in foot-notes to the Appendix-Tables, unless considered quite immaterial.

5. *Population.*

There are official returns, or estimates, of the population at the middle of each year for the whole period of our review—for

England and Wales, for Scotland, and for Ireland, each separately, and for the United Kingdom collectively.*

In these records we have quite sufficiently accurate information as to the total number of mouths there are to feed in each separate part of the kingdom, and in the whole collectively, each year. As, however, the figures apply to the middle of each year we have estimated the number required to be fed by the home-produce of each harvest and the imports of the twelve months or harvest-year following (Sept. 1 to Aug. 31), by adding to the number recorded for the preceding midsummer two-thirds of the difference between that figure and the number set down for the next midsummer, thus bringing the estimate up to the middle of the harvest-year; that is, to the end of February. For example, the population set down as the consumers from September 1st, 1852, to August 31st, 1853, is calculated by adding to the official estimate for midsummer 1852 two-thirds of the difference between that estimate and the number given for midsummer 1853, and so on.

But in estimating the quantity of wheat required by a given population by reference to the amounts of flour and bread recorded in the dietaries of persons of different classes, sexes, and ages, it is obviously necessary to take into account the number of each description comprised in the total population. It happens, however, that the published records of dietaries do not enable us to go more into detail in the classification of consumers, so far as sex and age are concerned, than is represented by the division into—males under fifteen years, males over fifteen years, females under fifteen years, and females over fifteen years.

The following table shows the proportion of each of the above divisions in 100 of the population of England and Wales, in 1866; and it is only for England and Wales that we have attempted to estimate the consumption per head, according to the entries of bread and flour in published dietaries.

PER CENT. in the TOTAL POPULATION of ENGLAND and WALES (1866).

AGES.		MALES.	FEMALES.	TOTAL.
Under 15 years	.. ..	18·1	18·0	36·1
Over 15 years	.. ..	30·4	33·5	63·9
Totals	.. ..	48·5	51·5	100·0

* Twenty-ninth Annual Report of the Registrar-General, &c., &c. (1868), p. lxx.

6. *Estimated Consumption of Wheat per Head of the Population per Annum.*

In 1855* we published estimates of the average amounts of certain constituents of food consumed in 24 hours by individuals of both sexes and different ages. The results were obtained by the calculation of 86 different dietaries, arranged in 15 divisions, according to sex, age, activity of mode of life, and other circumstances. It was obvious that the data were applicable for arriving at some conclusion as to the amount of the products of wheat grain—flour and bread—consumed by each individual of the population.

The average amount of wheat consumed per head of the population, per annum, had been variously estimated at from 6 to 8 bushels for the whole of Great Britain.† According to the amounts of bread and flour registered in the dietaries selected for the calculation, we were led, at the date referred to, to conclude that not more than from $6\frac{1}{2}$ to $6\frac{3}{4}$ bushels of wheat were consumed per head of the population in England. On reconsideration, with a view to this paper, of the data adopted, and of the calculations then made, we are disposed to conclude that the evidence supplied by the dietaries then consulted indicates an average consumption of wheat per head, of the mixed population of both sexes and all ages, of under rather than over 6 bushels per annum.

The records of dietaries, even now at command, are by no means so satisfactory as might be desired, as a basis for the calculation of the consumption of wheat by an average individual of the population. But, on a careful consideration of the more recent data, and a comparison with the old, the result so indicated is that the consumption of wheat in England and Wales is over, but probably not much over, 6 bushels per head per annum. Against this estimate founded on dietaries, there will be found in detail in Appendix-Table I. (p. 36), and in summary overleaf, the results arrived at on the basis of the population and of the amounts of the home-produce and the net imports of wheat each year.

For Scotland and Ireland each separately, as well as for Great Britain and the United Kingdom, the average consumption of wheat per head can only be estimated on the basis of the population and the amounts of the home and foreign supplies. The results of all the estimates so made will be found in the respective Appendix-Tables; but the following is a summary of them:—

* 'On the Sewage of London,' Journal Society of Arts, March 9, 1855.

† Porter's 'Progress of the Nation,' 1851.

22 *Home Produce, Imports, and Consumption of Wheat.*

ESTIMATED CONSUMPTION of WHEAT per Head, per Annum.

	ENGLAND AND WALES.	SCOTLAND.	GREAT BRITAIN.	IRELAND.	UNITED KINGDOM.
	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.
First 8 years, 1852-53 to } 1859-60 }	5·9	4·2*	5·7	2·7	5·1
Second 8 years, 1860-61 to } 1867-68 }	6·3	4·2	6·0	3·3	5·5
Sixteen years, 1852-53 to } 1867-8 }	6·1	4·2	5·9	3·0	5·3

We have now explained in detail the nature of the data at command in relation to—the area under wheat; the average yield per acre; the aggregate home-produce, and the amount of it available for consumption; the quantities imported; the number of consumers; the probable amount required, or the amount available, per head—in each main division of the United Kingdom, and in the whole collectively.

The result is that, unless we except Ireland, we have, neither in reference to the separate portions, nor to the whole of the United Kingdom, the necessary data relating to all the various elements of the question. Such, however, is the best material at our command; and should some of the results to which the application of it leads betray obvious inconsistencies, we shall at least have succeeded in adding one more argument to the many hitherto adduced in favour of the official collection and publication of complete agricultural statistics.

7. *General Considerations.*

The following considerations will show how impossible it is, without accurate information on points in reference to which we do not possess it, to determine accurately, either the amount of wheat available, or the amount actually consumed, within the limits of any individual year.

However correctly the *average* area under wheat over a series of years may be estimated for either, or for all of the main divisions of the kingdom, the breadth is known to vary very considerably from year to year, according to price, stocks of home and foreign wheat, prospect of foreign supplies, and the characters of the season and consequent condition of the land at the time for sowing. Thus, it is known that the area was unusually small in 1853; and it was reported to be deficient in 1861, and more or less over the average in 1852, 1854, 1855, 1856, 1857, 1862,

* Assumed, according to the average of the 6 years, 1862-63 to 1867-68, for which returns of the separate imports into Scotland are available.

1863, and 1864; whilst, owing both to the favourable character of the seed time, and the high price of wheat, the area of the crop just harvested (1868) was, it is believed, very large. But of the actual or numerical result of all the above influences, upon which so materially depends the accuracy of any estimates of the home-produce in any particular year, we have had absolutely no information whatever in regard to England and Wales prior to 1866, very incomplete records in regard to Scotland, but much more complete so far as Ireland, about one-tenth of the whole, is concerned.

With regard to the *average yield of wheat per acre* in any individual year, there is, so far as England and Wales and Scotland are concerned, even less to rely upon in the way of *actual record*, than in regard to area.

The *harvest-year*, which is the period of consumption to be provided for, may be several weeks shorter or longer, according to the earliness or the lateness of the two consecutive harvests. The season just past is a striking illustration of this.

The stocks of home-produce in the stack-yard and the barn, and of foreign wheat in the granaries, is very different at one harvest period and at another. The amount carried over for consumption from one harvest-year to another will, therefore, vary very much accordingly. The quantity held over by the farmer will, other things being equal, be at a maximum when the prices of grain are low, and two or more good harvests succeed each other. It was estimated that at the harvest of 1865 there still remained over from the extraordinary crop of 1863, and the abundant crop of 1864, wheat equal to from one-third to one-half of an average crop; and even at the harvest of 1866 some of the crop of 1863 remained unthrashed.

On the other hand, when wheat is kept for two or three years, a considerable, but an unascertainable, loss results from destruction by vermin.

The *weight per bushel of the grain* will very materially affect the amount of human food provided in a given measure of it. Thus, not to take extreme ranges, a quarter of wheat at the adopted average of 61 lbs. per bushel, will weigh 488 lbs. But if the bushel weigh only 59 lbs, the quarter will weigh only 472 lbs.; or if the bushel weigh 63 lbs. the quarter will weigh 504 lbs. There is here, then, a difference in the weight of a quarter of wheat of 16 lbs., or about $3\frac{1}{2}$ per cent. below the average if the weight per bushel be only 59 lbs., or of 16 lbs., or about $3\frac{1}{2}$ per cent. over the average if the bushel weigh 63 lbs.; obviously, therefore, a difference of 32 lbs. per quarter, or nearly 7 per cent., between a crop of 59 lbs. and one of 63 lbs. per bushel. To illustrate the point in another way: if the average produce for the year were 28 bushels per acre, and the weight

per bushel only 59 lbs., it would only yield about as much flour as 27 bushels of the average weight of 61 lbs.; but if the weight per bushel were 63 lbs., the crop of 28 bushels would yield about as much flour as 29 bushels at the average of 61 lbs. per bushel.

Not only will there be a considerable difference in the amount of wheat to grind in a given measure of it, according to the weight per bushel, but there will, generally, be not only a lower percentage of flour, but flour of a lower quality, from the wheat of the lower weight per bushel. Then, again, the lower the quality of the wheat the more, probably, will be dressed out and used for other purposes than human food.

When, on the other hand, the supplies are large, and prices consequently low, a larger proportion of the inferior samples of wheat will be given to the animals on the farm.

Lastly, the consumption per head of the population will vary, not only according to the amount of employment, and to the price of wheat itself, but to that of other consumable articles. If other food-stuffs are cheap a low price of wheat may but little increase its consumption; but if other articles are dear a relatively low price of wheat will increase its consumption. Again, if both wheat and other articles are dear, it may be a question whether the consumption of the first necessary of life—*bread*—will not be increased rather than diminished, to compensate for the necessary abstinence from, or limitation in the use of, the less absolutely essential food-stuffs.

The above considerations are sufficient to show that, even if we had complete and reliable information as to the area under wheat, the yield per acre, the imports, and the population each year, there are still other elements in regard to which information would be required, before really trustworthy conclusions could be formed on some important points. Thus, as will be seen presently, the inadequacy of the data in regard to individual years is well illustrated by the great difference which the results of the calculations, as they stand, would indicate in the amount of wheat consumed per head in one year compared with another.

THE RESULTS.

The following Table brings together some of the results distributed in the several Appendix-Tables in regard to the number of bushels *available* for consumption per head of the population, in each main division of the United Kingdom, and in the whole together, within each harvest-year. It also shows the proportion per cent. in which the *available* supply was due to home and foreign sources respectively.

TABLE III.—ESTIMATED QUANTITY OF WHEAT available per head of the POPULATION, within each Harvest-year;
(September 1—August 31).

	ENGLAND AND WALES.			SCOTLAND.			GREAT BRITAIN.			IRELAND.			UNITED KINGDOM.		
	Per Cent.		Total per head.	Per Cent.		Total per head.	Per Cent.		Total per head.	Per Cent.		Total per head.	Per Cent.		Total per head.
	From Home-produce.	From Imports.		From Home-produce.	From Imports.		From Home-produce.	From Imports.		From Home-produce.	From Imports.		From Home-produce.	From Imports.	
1852-3	68	32	Bushels. 5.7	36	64	Bushels. 5.4	65	35	Bushels. 2.4	58	42	Bushels. 4.7	64	36	Bushels. 4.7
1853-4	64	36	5.3	31	69	5.2	60	40	2.1	67	33	4.5	60	40	4.5
1854-5	91	9	6.8	36	64	6.5	86	14	2.4	71	29	5.6	84	16	5.6
1855-6	87	13	5.3	38	62	5.2	81	19	2.6	73	27	4.6	80	20	4.6
1856-7	79	21	5.7	52	48	4.8	76	24	2.6	77	23	4.9	75	25	4.9
1857-8	76	24	7.5	45	55	7.1	73	27	2.8	71	29	6.2	74	26	6.2
1858-9	82	18	6.3	48	52	6.1	79	21	3.5	63	37	5.5	76	24	5.5
1859-60	82	18	5.0	36	64	4.9	76	24	3.5	51	49	4.6	72	28	4.6
1860-1	52	48	6.3	29	71	6.1	51	49	3.4	47	53	5.6	50	50	5.6
1861-2	61	39	6.4	31	69	6.1	59	41	3.5	29	71	5.6	55	45	5.6
1862-3	65	35	4.4	32	68	6.7	63	37	3.2	25	75	6.0	58	42	6.0
1863-4	78	22	4.6	37	63	7.2	75	25	3.3	33	67	6.5	71	29	6.5
1864-5	83	17	3.9	36	64	6.1	79	21	3.3	33	67	5.6	73	27	5.6
1865-6	72	28	4.9	22	78	5.9	68	32	3.2	34	66	5.4	65	35	5.4
1866-7	65	35	3.4	24	76	5.2	61	39	3.2	31	69	4.8	58	42	4.8
1867-8	55	45	4.0	18	82	5.0	52	48	3.2	28	72	4.7	49	51	4.7
Mean	73	27	4.2	34	66	5.9	69	31	3.0	49	51	5.3	67	33	5.3

* Assumed, according to the average of the 6 years, 1862-63 to 1867-68, for which returns of the separate imports into Scotland are available.

Obviously, from the various causes which have been enumerated, the figures can only show the quantities *available* each year, as represented by the estimated yield of one harvest and the imports up to the next harvest, and *not* the amounts actually consumed within the limits of each harvest-year.

Taking our illustrations on the point from the figures relating to England and Wales, it is obvious, if we assume 6.1 bushels of wheat per head per annum to represent the average consumption, that in the two harvest-years 1852-3 and 1853-4, either the total produce must have been greater than estimated, or the supplies held over from the immediately preceding years must have been considerable, or the rate of consumption at that period must have been considerably below the average of the sixteen years. According to published reports, a good deal of the crop of 1849 remained at the harvest of 1850; whilst the imports were very large, and foreign wheat had accumulated up to the harvest of 1851, though the home-produce was said to be closely used up. The reports would show, however, that stocks of both home and foreign wheat were, perhaps, more than usually small at the harvest of 1852. Most probably the consumption per head was lower at that date; but we must confess to the want of sufficient information to enable us to decide upon the exact explanation of the facts.

With regard to none of the other years is there any difficulty in showing how the estimated average requirement for the period could be met; but rather, on the contrary, during some of the later years, the figures indicate a surplus which the mere average consumption would not dispose of.

Thus, the two deficient years of 1855-6 and 1856-7 stand between the abundant harvest of 1854, and the both early and abundant one of 1857. Again, the deficiency of the harvest-year 1859-60, appears to be compensated by the surplus of the two preceding years. Lastly, the deficiency within the harvest-years of 1866-7 and 1867-8, is, apparently, more than compensated by the surplus available for carrying on from year to year since 1861-2. Indeed, according to the figures, we ought at the present time, to have considerable stocks of either home or foreign wheat on hand. There is, however, no reason to suppose that such exist. So far as the harvest-year just past (1867-8) is concerned, the high prices are sufficient to show that there was throughout a less than average supply; but it must not be forgotten that the period of consumption has been considerably shortened both by the somewhat late harvests of 1867, and the very unusually early one of 1868; and hence the figure representing the total quantity available per head has in reality had to meet the requirements of considerably less than the assumed period of twelve months.

The great fluctuation in the proportion in which the home supplies provide the amount required of the staple food of the population from year to year, chiefly due to season, but partly also to variation in area, and partly to gradual increase in population, is strikingly illustrated by the figures given in Table III.; but more strikingly still by those in Table IV., below; which shows the proportion in which the estimated produce of wheat of each harvest provided the amount required during the succeeding harvest-year, supposing the amount per head required in each individual year to be represented by the average amount per head per annum over the sixteen years.

TABLE IV.—PROPORTION supplied by the estimated Home-produce each Year, in 100 of the estimated AVERAGE requirement per Head of the Population.

HARVEST YEARS.	ENGLAND AND WALES.	SCOTLAND.	GREAT BRITAIN.	IRELAND.	UNITED KINGDOM.
1852-3	64	36	59	47	57
1853-4	56	31	53	47	51
1854-5	102	36	95	57	89
1855-6	75	38	71	64	70
1856-7	74	52	71	67	70
1857-8	93	45	88	67	87
1858-9	85	48	81	74	79
1859-60	67	36	63	60	62
1860-1	54	29	55	54	53
1861-2	64	31	61	34	58
1862-3	75	33	71	27	66
1863-4	97	40	92	37	87
1864-5	87	33	81	37	77
1865-6	72	26	68	37	66
1866-7	57	19	54	34	53
1867-8	46	17	44	30	43
Mean	73	34	69	49	67

Thus, according to the estimates, the home-produce in England and Wales was in 1854 fully equal, in 1863 nearly, and in 1857, not far short of, the estimated average requirements of their populations. In 1853, in 1860, and in 1866, on the other hand, little more than half, and in 1867 even less than half of the wheat required by the population of England and Wales was home-produced.

The figures relating to the United Kingdom collectively, show contrasts nearly, though not quite as great; and it is to be borne in mind that it is in relation to the whole kingdom that the indications are of the greatest interest and importance. In 1854, 1857, and 1863, the home-produce of the United Kingdom supplied, according to the estimates, from 87 to 89 per cent. of the average amount of wheat required by the total population;

but in 1867 only 43 per cent., and in 1852, 1853, 1860, 1861, and 1866, only between 50 and 60 per cent.

In reference to the figures in the Tables (III and IV), and to the above comments upon them, the great increase in the number of consumers within the period must not be overlooked. Thus, although the crop of 1863 is estimated to have been considerably greater than that of 1854, it does not, owing to the increase of population during the nine years, supply so large a proportion of the wheat estimated to be required, as does the smaller crop with the smaller population nine years previously.

The fluctuations due to season alone, apart from change of area or increase of population, is better shown by reference to the estimated yield per acre. The column of estimated average yield per acre each year in England and Wales (Appendix-Table I., p. 36) will well illustrate the extent of this variation. Thus the average yield per acre is estimated at only $20\frac{1}{2}$ bushels in 1853, and at $39\frac{3}{4}$ bushels in 1863. That is to say, there was a difference in the estimated yield per acre in the two years of $19\frac{1}{2}$ bushels, equal to nearly $2\frac{1}{2}$ quarters, or about two-thirds of an average crop, due to variation of season alone. The average yield over the 16 years was $28\frac{3}{4}$ bushels; it results, therefore, that the crop of 1853 was $8\frac{1}{2}$ bushels below, and that of 1863 11 bushels above the average. The result is, that whilst a very bad season may yield only about, or even less than, half of the total wheat required by the population for a year's consumption, an average crop has (according to the population at the time) provided from two-thirds to three-fourths, and an extremely good one not much short of the whole required. A consideration of these facts is sufficient to show the vast importance, at once to the producer, the importer, and the consumer, of correct and early information as to the quantity and quality of the crop of the country.

So much for the proportion, and especially the variation in the proportion from year to year, according to season, increase of population, and other circumstances, in which the home-produce of wheat supplies the estimated average amount required. There remains to be considered the equally important complementary element of the question—what proportion of the wheat consumed is obtained from foreign sources?

Taking the average of the whole period, the percentage of the total wheat consumed which is provided by imports is, of course, the difference between that supplied by the home-produce and 100. But, inasmuch as the sum of the home-produce and the imports of the harvest-year is sometimes more and sometimes less than the average amount required, it is obvious that the difference between the *average* total amount required taken as

100, and the proportion of it which is *available* each year from home supplies (as shown in Table IV.) does not show the proportion actually supplied from foreign sources within each individual year.

The following Table shows the proportion in which the actual imports within each harvest-year provided the estimated *average* amount consumed per head of the population. The imports being much more of a hand-to-mouth supply than the home-produce, they may be supposed to be much more nearly consumed within the period for which they are set down ; and, consequently, the figures in the following Table relating to the imports will so much the more closely represent the actual dependence on imports in each individual year, than do the figures in Table IV. show the percentage in which the requirements of consumption were actually met by the home-supplies within each year :—

TABLE V.—PROPORTION supplied by the Imports each Year in 100 of the estimated AVERAGE requirement per Head of the Population.

HARVEST YEARS.	ENGLAND AND WALES.	SCOTLAND.	GREAT BRITAIN.	IRELAND.	UNITED KINGDOM.
1852-3	30	64	32	33	32
1853-4	31	69	36	23	34
1854-5	10	64	15	23	17
1855-6	11	62	17	23	17
1856-7	20	48	22	19	23
1857-8	30	55	32	26	30
1858-9	18	52	22	43	25
1859-60	15	64	20	56	25
1860-1	49	71	51	59	53
1861-2	41	69	42	83	47
1862-3	41	71	42	79	47
1863-4	28	69	31	73	36
1864-5	18	60	22	73	28
1865-6	28	90	32	69	36
1866-7	31	62	34	73	38
1867-8	38	79	41	76	45
Mean	27	66	31	51	33

Looking for our illustrations to the column relating to the United Kingdom, in relation to which the subject is of the greatest national importance, it is seen that in 1854-5 and 1855-6 the imports supplied only 17 per cent. of the estimated average annual requirements for the population of the period ; whilst, in 1860-61 they supplied 53 per cent., in 1861-2 and 1862-3 47 per cent., and in 1867-8 45 per cent.

The average amount of wheat supplied by imports to the United Kingdom over the whole period of sixteen years is 33 per cent. of the total amount estimated to have been consumed. It

is a significant fact that only once during the first eight years of the sixteen was more than this average proportion provided by imports, and that was after the exceptionally bad harvest of 1853; notwithstanding which, only 1 per cent. more, or only 34 per cent. of the total for the period (taken at the average rate per head), was imported. On the other hand, only once during the last eight of the sixteen years were the imports below the average proportion of 33 per cent. of the total estimated to be required; whilst in four out of the other seven they exceeded the average proportion by from one-third to one-half or more. This is the case in spite of the fact of a somewhat higher yield per acre during the last than during the first eight years. Nor can it be accounted for by the degree in which it is assumed that the area under wheat has diminished of late years. It is without doubt to a great extent due to increase of population; but if the estimates are to be relied upon, there has also been an appreciable increase in the consumption of wheat per head of late years; as will be seen by reference to the summary of the results on this head given at p. 22.

To conclude in reference to the results recorded in Table V., it may be observed that, whilst taking the average of the sixteen years the imports of wheat to the United Kingdom collectively, supplied only 33 per cent. of the whole required; 51 per cent. of the estimated consumption in Ireland over the same period, and only 31 per cent. of that in Great Britain, were supplied by imports. In each division of the country, however, the proportion of the whole consumed has considerably exceeded the average during the later years, and this is more especially the case so far as Ireland is concerned.

Summary and General Conclusions.

Whatever anomalies may appear on consideration of the results to which our data lead us in regard to individual years, little doubt need be entertained as to the approximate correctness and the value of the average results over the sixteen years, or even over the first eight and the second eight years of the period, so far as most, if not all, of the main points—whether relating to home-produce, imports, or consumption—are concerned.

The following Table (VI.) brings together at one view the average results relating to each of the separate points of the inquiry, for the first half, the second half, and the total period of sixteen years.

It would lead into far too long a discussion were we to attempt to direct attention in detail to the many points of interest brought to view in this very comprehensive Summary Table. However interesting in certain points of view the average results

Home Produce, Imports, and Consumption of Wheat.

TABLE VI.—SUMMARY OF RESULTS RELATING TO HOME-PRODUCE, IMPORTS, AND CONSUMPTION OF WHEAT.

Periods.	ESTIMATED HOME-PRODUCE.			AVAILABLE FOR CONSUMPTION.			POPULATION (middle of Harvest- of Year).				AVAILABLE FOR CONSUMPTION.			Average Price per Quarter.
	Area under Wheat.	Average Yield per Acre.	Total Home- produce.	Home- produce, less 24 Bushels per Acre for Seed.	Imports, less Exports.	Total.	Population (middle of Harvest- Year).	Per Hendl.		Per Cent.				
								From Home- produce.	From Imports.	From Home- produce.	From Imports.			
ENGLAND AND WALES.														
First 8 Years, 1852-3 to 1859-60 Average per Annum.	Acres.	Bushels.	Quarters.	Quarters.	Quarters.	Quarters.	Bushels.	Bushels.	Bushels.	79	21	21	57 7	
	3,430,322	28½	12,164,941	11,190,153	3,010,587	14,200,760	4.7	1.2	5.9	66	34	62 4		
	3,289,868	29	11,942,665	11,017,392	5,365,887	16,386,279	4.2	2.1	6.3	66	34	62 4		
16 Years, 1852-3 to 1867-8 .	3,360,090	28½	12,048,803	11,103,777	4,189,737	15,293,514	4.4	1.7	6.1	73	27	55 0		
SCOTLAND.														
First 8 Years, 1852-3 to 1859-60 Average per Annum.	207,169	26½	684,721	626,455	946,135	1,672,690	1.7	2.5	4.2	40	60	57 7		
	139,665	29	506,765	467,487	1,173,297	1,610,784	1.2	3.0	4.2	29	71	57 7		
	173,412	27½	596,743	546,971	1,069,716	1,606,687	1.4	2.8	4.2	34	66	57 7		
GREAT BRITAIN.														
First 8 Years, 1852-3 to 1859-60 Average per Annum.	3,637,491	28½	12,839,662	11,816,618	3,956,722	15,773,340	4.3	1.4	5.7	75	25	57 7		
	3,429,513	29	12,449,430	11,484,879	6,542,184	18,097,063	3.8	2.2	6.0	64	36	57 7		
	3,533,502	28½	12,644,546	11,650,748	5,249,453	16,900,201	4.1	1.8	5.9	69	31	57 7		
IRELAND.														
First 8 Years, 1852-3 to 1859-60 Average per Annum.	464,669	26½	1,471,117	1,313,241	696,062	2,039,303	1.8	0.9	2.7	66	34	57 7		
	323,498	21½	869,817	769,833	1,655,676	2,324,409	1.1	2.2	3.3	33	67	57 7		
	389,084	23½	1,165,467	1,066,037	1,123,819	2,181,856	1.4	1.6	3.0	49	51	57 7		

UNITED KINGDOM.

over the whole sixteen years may be, it is obvious that the real interest centres, so far as most of the subjects are concerned, much more in the direction and the degree of progress from time to time. Leaving the reader to study the evidence of progress in more detail in the Appendix-Tables, it must suffice here to comment on some of the most prominent points which a comparison of the results during the first half and the second half of the period of sixteen years illustrates.

Enough has been said already in regard to the sources and the character of the data upon which the calculations are founded, to indicate on what points the results must be accepted with some reservation. With this precautionary observation we may proceed briefly to direct attention to some of the most important facts which the figures bring to light.

In regard to England and Wales the result is that, during the last eight years as compared with the previous eight, the area under wheat is estimated to have diminished by about 4 per cent., the yield per acre to have increased by little over 2 per cent., and the total produce accordingly diminished by about $1\frac{1}{2}$ per cent. The diminution in aggregate home-produce available as human food amounts during the last eight years as compared with the previous eight, to $1\frac{1}{2}$ per cent.; whilst there is an increase in the imports during the same period of nearly 80 per cent.—the result being an increase in the estimated total wheat consumed in England and Wales during the last eight years as compared with the former eight, of between 15 and 16 per cent. Against this increase in consumption, however, there is an increase of population of little more than 9 per cent. The result is a diminution in the proportion in which the total consumption per head is supplied from home resources from 79 to 66 per cent., and an increase in the proportion in which the whole is supplied by imports from 21 to 34 per cent. Lastly, according to the figures, the actual consumption of wheat per head of the population has increased by nearly 6 per cent.

Since the apportionment between England and Wales on the one hand, and Scotland on the other, of the imports into Great Britain during the first ten years of the sixteen, was, to a great extent, arbitrary, as already explained, and since, owing to the comparatively small figures for Scotland, any error in the apportionment would more affect the results in regard to it than those relating to England and Wales, the indications of the figures must of course be accepted with more of caution. It may be stated in general terms, however, that whilst the area under the crop and the total home-produce of wheat in Scotland would appear to have diminished during the last eight years as compared with the former eight, very much more, proportionally,

than in England and Wales, the imports, on the other hand, must be supposed to have considerably increased; though whether in a greater or a less proportion than in England and Wales, is, however, doubtful; as also is the indication of the figures that the consumption of wheat per head of the population has not increased.

The results relating to Great Britain are on most points more satisfactory than those relating either to England and Wales, or to Scotland separately. The conclusions in regard to Great Britain are, that, comparing the two periods of eight years each, the area has diminished during the latter half by nearly 6 per cent., the yield per acre increased by rather over $2\frac{1}{2}$ per cent., and the aggregate home-produce available as human food diminished by about $2\frac{1}{2}$ per cent. On the other hand the imports have increased by more than 65 per cent., and the total wheat consumed by about 14 per cent. The population has, however, increased by scarcely $8\frac{1}{2}$ per cent. The general result is an increase in consumption per head of more than 5 per cent., a decrease from 75 to 64 per cent. in the proportion in which the total consumption per head is supplied by home resources, and an increase from 25 to 36 per cent. in the proportion in which it is supplied from imports.

The records both as to home-produce and imports are more complete for Ireland than for any other part of the United Kingdom. The comparison of the results relating to the two periods of eight years each shows a diminution of area under wheat during the latter period of about 29 per cent., a diminution in yield per acre of about 17 per cent., and a diminution of home-produced wheat available for consumption of about 43 per cent. Against this very marked reduction in the home supplies of wheat in Ireland we have an increase in the imports of about 123 per cent.; the result being an increase in the total wheat consumed in the country of about 14 per cent., whilst the population has diminished between 5 and 6 per cent. The general result is an increase in the total consumption of wheat per head in Ireland of more than 20 per cent.; and, of the total amount consumed per head, there has been a diminution in that supplied by home produce from 66 to 33 per cent., and an increase in that supplied by imports from 34 to 67 per cent.

Obviously, the point of greatest national interest and importance to consider is the progressive or retrogressive position of the United Kingdom as a whole in regard to the several elements of this wide question. Comparing the last eight with the preceding eight years, the figures show a diminution of area under wheat in the United Kingdom during the later period of between 8 and 9 per cent., an increase in yield per acre of about $1\frac{1}{2}$ per cent., and

a diminution in the total wheat supplied from home produce of nearly 7 per cent. There is, on the other hand, an increase in the foreign supplies of about 74 per cent. The result is an increase in the aggregate amount of wheat consumed in the United Kingdom of between 14 and 15 per cent., with an increase of population of only about $5\frac{1}{2}$ per cent. Or, looking to the consumption per head of the population, the proportion provided by the home supplies has diminished from 73 to 60 per cent.; whilst that supplied by foreign produce has increased from 27 to 40 per cent.; the result of the whole being an increase in the total consumption per head during the later period of between 8 and 9 per cent.

The main conclusions from the whole inquiry, more especially those brought out by the comparison of the results relating to the first and second periods of eight years each, may be briefly enumerated as follows:—

1. There has been a reduction in the area under wheat in each of the three main divisions of the United Kingdom; very large, proportionally, in both Scotland and Ireland, but comparatively small in England and Wales.

2. There has, pretty certainly, been a small increase in the yield per acre in England and Wales, and probably in Scotland also, but a marked diminution in Ireland; leaving, however, still a small increased yield per acre in the United Kingdom collectively.

3. There has been a diminution in the aggregate of home-produced wheat in the United Kingdom; proportionally small in England and Wales, very considerable in Scotland, and more considerable still in Ireland.

4. Throughout the United Kingdom the imports have increased enormously of late years, and in a much greater proportion in Ireland than in Great Britain.

5. The aggregate amount of wheat consumed annually in the United Kingdom has increased very considerably; and the ratio of increase would appear to be much the same in Great Britain and in Ireland.

6. In the United Kingdom, collectively, the population has increased considerably; in much the greater proportion in England and Wales, less than half as rapidly in Scotland, whilst in Ireland there has been a diminution.

7. The proportion of the total wheat consumed per head of the population, which is provided by home produce, has much diminished throughout the United Kingdom; in by far the greatest degree in Ireland, very largely in Scotland, but much less in England and Wales than in either.

8. In every division of the United Kingdom the proportion of the total wheat consumed per head which is supplied from foreign sources, has enormously increased; in by far a greater degree in Ireland than in either of the other divisions of the Kingdom.

9. The actual consumption of wheat per head in the United Kingdom has notably increased; more than 20 per cent. in Ireland, but little more than 5 per cent. in Great Britain.

10. Taking the average of the last eight years the figures show the annual consumption of wheat per head of the population to have been about $6\frac{1}{2}$ bushels in England and Wales, scarcely $4\frac{1}{2}$ bushels in Scotland, and only about $3\frac{1}{2}$ bushels in Ireland; or, for the whole of Great Britain, about 6 bushels, and for the whole of the United Kingdom about $5\frac{1}{2}$ bushels per head.

11. Taking the population of the United Kingdom (including the Islands in the British seas) to be at the present time about 30,800,000, and the average consumption of wheat per head per annum to be $5\frac{1}{2}$ bushels, this gives a present requirement of rather more than 21 million (21,175,000) quarters.

12. It may be estimated that, at the recent rate of increase, the population of the United Kingdom will have increased by rather more than 1 million at the end of the next five years; and taking the rate of consumption per head as before, at $5\frac{1}{2}$ bushels, there would then be required nearly 22 million quarters; or, assuming the consumption to have increased to $5\frac{3}{4}$ bushels per head, the requirement would then be nearly 23 million quarters.

13. Unless the home-produce of wheat in the United Kingdom available as human food (about $12\frac{1}{4}$ million quarters per annum over the last eight years) should increase, it is obvious that, even at the lower rate of consumption above supposed ($5\frac{1}{2}$ bushels per head), there will be required over the next five years an average importation of between 9 and 10 million quarters annually.

Rothamsted, September, 1868.

APPENDIX—TABLE I.
PARTICULARS OF HOME-PRODUCE, IMPORTS, CONSUMPTION, AND AVERAGE PRICE OF WHEAT.
ENGLAND AND WALES.

Harvest Years. Sept. 1 to Aug. 31.	ESTIMATED HOME-PRODUCE.			AVAILABLE FOR CONSUMPTION.				Population (middle of Harvest Year).	AVAILABLE FOR CONSUMPTION PER HEAD.			Average Price per Quarter.
	Area under Crop.	Average Yield per Acre.	Total Home-produce.	Home-produce, less 2½ Bushels per Acre for Seed.	Imports, less Exports.	Total.	Quarters.		From Home- produce.	From Imports.	Total.	
	Acrea.	Bushels.	Quarters.	Quarters.	Quarters.	Quarters.	Quarters.		Bushels.	Bushels.	Bushels.	z. d.
1852-3	3,493,665	22½	9,825,933	8,843,340	4,116,933	12,960,273	18,333,980		3·9	1·8	5·7	43 10
1853-4	3,475,567	20½	8,797,529	7,820,026	4,471,379	12,291,405	18,545,663		3·4	1·9	5·3	73 7
1854-5	3,457,469	36½	15,504,588	14,532,175	1,490,037	16,022,212	18,758,103		6·2	0·6	6·8	70 1
1855-6	3,439,371	27½	11,769,098	10,801,775	1,720,657	12,522,432	18,971,275		4·6	0·7	5·3	73 8
1856-7	3,421,273	27½	11,653,711	10,691,478	2,954,355	13,645,833	19,185,148		4·5	1·2	5·7	60 1
1857-8	3,403,175	35	14,888,891	13,931,748	4,382,310	18,264,058	19,399,699		5·7	1·8	7·5	47 8
1858-9	3,385,077	32½	13,751,875	12,799,822	2,735,758	15,535,580	19,614,898		5·2	1·1	6·3	43 8
1859-60	3,366,979	26½	11,047,900	10,100,937	2,263,270	12,364,207	19,830,709		4·1	0·9	5·0	48 3
1860-1	3,348,881	22½	9,314,075	8,372,202	7,576,309	15,948,511	20,047,114		3·3	3·0	6·3	55 2
1861-2	3,330,783	26½	10,877,086	9,940,305	6,197,850	16,138,155	20,264,083		3·9	2·5	6·4	58 2
1862-3	3,312,685	30½	12,681,372	11,749,679	6,313,301	18,062,980	20,481,580		4·6	2·5	7·1	47 8
1863-4	3,294,587	39½	16,369,979	15,443,376	4,327,680	19,771,056	20,699,584		5·9	1·7	7·6	41 0
1864-5	3,276,489	36	14,744,201	13,822,688	2,992,239	16,814,927	20,918,066		5·3	1·1	6·4	40 1
1865-6	3,258,391	31½	12,677,177	11,760,755	4,372,972	16,133,727	21,136,995		4·4	1·7	6·1	46 6
1866-7	3,240,293	25½	10,328,434	9,417,102	5,064,815	14,481,917	21,356,345		3·5	1·9	5·4	61 7
1867-8	3,256,738	21	8,548,990	7,633,027	6,105,872	13,738,899	21,576,087		2·8	2·3	5·1	68 5
1868-9	(3,360,090)*	(34½)	(14,542,890)	(13,597,865)	..	..	(21,798,090)		(5·0)	..	..	..
Means 52·3 to 1867·8	3,360,090	28½	12,048,803	11,103,777	4,189,737	15,293,514	19,944,958		4·4	1·7	6·1	55 0

* As it is supposed that the area was large, the mean of the 16 years, instead of the mean of the Returns for the two preceding years, is adopted here.

APPENDIX—TABLE II.
PARTICULARS OF HOME-PRODUCE, IMPORTS, AND CONSUMPTION OF WHEAT.
SCOTLAND.

Harvest Year.	ESTIMATED HOME-PRODUCE.			AVAILABLE FOR CONSUMPTION.			AVAILABLE FOR CONSUMPTION PER HEAD.		
	Area under Crop.	Average yield per Acre.	Total Home- Produce.	Home-produce, less 2½ Bushels per Acre for Seed.	Imports, less Exports.	Total.	Population (middle of harvest year).	From Home- produce.	From Imports.
	Acres.	Bushels.	Quarters.	Quarters.	Quarters.	Quarters.		Bushels.	Bushels.
1852-3	211,500	22½	594,844	535,360	1,004,051	1,539,411	2,932,212	1.5	2.7
1853-4	211,500	20½	535,359	475,875	1,074,215	1,550,090	2,952,552	1.3	2.9
1854-5	188,816	28½	606,085	558,774	1,001,411	1,560,185	2,971,780	1.5	2.7
1855-6	191,301	26½	632,884	579,081	990,600	1,569,681	2,989,869	1.6	2.6
1856-7	263,328	27½	908,869	834,808	743,760	1,578,568	3,006,797	2.2	2.0
1857-8	223,153	27½	769,973	706,611	880,226	1,586,837	3,022,517	1.9	2.3
1858-9	199,781	32½	811,610	755,422	859,053	1,594,475	3,037,096	2.0	2.2
1859-60	188,571	26½	618,749	565,713	1,035,762	1,601,475	3,050,429	1.5	2.7
1860-1	177,361	22½	493,285	443,402	1,164,499	1,607,901	3,062,668	1.2	3.0
1861-2	166,151	26½	542,587	495,857	1,120,200	1,616,057	3,078,204	1.3	2.9
1862-3	134,941	30½	593,134	549,557	1,158,136	1,707,693	3,095,560	1.4	3.0
1863-4	143,731	39½	714,163	673,738	1,118,241	1,791,979	3,112,916	1.7	2.9
1864-5	132,521	36	596,345	559,074	988,400	1,547,474	3,130,272	1.4	2.5
1865-6	121,311	31½	471,976	437,857	1,475,787	1,913,644	3,147,628	1.1	3.8
1866-7	110,101	25½	350,947	319,981	1,032,647	1,352,628	3,164,984	0.8	2.6
1867-8	111,118	21	291,685	260,432	1,328,465	1,588,897	3,182,340	0.7	-3.3
1868-9	(110,610)†	(34½)	(478,734)	(447,625)	..	..	(3,199,791)	(1.1)	..
Means 1852-3 to 1867-8	173,412	27½	595,743	546,971	1,059,716	1,606,687	3,058,616	1.4	2.8
									4.2

* Assumed, according to the average of the 6 years, 1862-3 to 1867-8, for which Returns of the separate imports into Scotland are available.

† The mean of the Returns for the two preceding years adopted here.

APPENDIX—TABLE III.
PARTICULARS OF HOME-PRODUCE, IMPORTS, AND CONSUMPTION OF WHEAT.
GREAT BRITAIN.

Harvest Years. Sept. 1 to Aug. 31.	ESTIMATED HOME-PRODUCE.			AVAILABLE FOR HOME CONSUMPTION.			POPULATION (middle of harvest years).		AVAILABLE FOR CONSUMPTION PER HEAD.		
	Area under Crop.	Average yield per Acre.	Total Home- Produce.	Home-produce, less 2½ Bushels per Acre for Seed.	Imports, less Exports.	Total.	Population (middle of harvest years).	Bushels.	From Home-produce.	From Imports.	Total.
	Acres.	Bushels.	Quarters.	Quarters.	Quarters.	Quarters.			Bushels.	Bushels.	Bushels.
1852-3	3,705,165	22½	10,420,777	9,378,700	5,120,984	14,499,684	21,266,192	3.5	1.9	5.4	
1853-4	3,687,067	20½	9,332,888	8,295,901	5,545,594	13,841,495	21,498,215	3.1	2.1	5.2	
1854-5	3,625,685	35½	16,110,673	15,090,949	2,491,448	17,582,397	21,729,893	5.6	0.9	6.5	
1855-6	3,630,672	27½	12,401,982	11,380,856	2,711,257	14,092,113	21,961,144	4.2	1.0	5.2	
1856-7	3,684,601	27½	12,562,580	11,526,286	3,698,115	15,224,401	22,191,945	4.2	1.3	5.5	
1857-8	3,626,328	34½	15,658,264	14,638,359	5,212,536	19,850,895	22,422,246	5.2	1.9	7.1	
1858-9	3,584,858	32½	14,563,485	13,555,244	3,574,811	17,130,055	22,651,994	4.8	1.3	6.1	
1859-60	3,555,550	26½	11,666,649	10,666,650	3,299,032	13,965,682	22,881,188	3.7	1.2	4.9	
1860-1	3,526,242	22½	9,807,360	8,815,604	8,740,808	17,556,612	23,109,782	3.1	3.0	6.1	
1861-2	3,496,934	26½	11,419,675	10,436,162	7,318,050	17,754,212	23,342,287	3.6	2.5	6.1	
1862-3	3,467,636	30½	13,274,506	12,299,236	7,471,437	19,770,673	23,577,140	4.9	2.5	6.7	
1863-4	3,438,318	39½	17,084,142	16,117,114	5,445,921	21,563,035	23,812,500	5.4	1.8	7.2	
1864-5	3,409,010	36	15,340,546	14,381,762	3,990,699	18,362,461	24,048,338	4.8	1.3	6.1	
1865-6	3,379,702	31½	13,149,153	12,198,612	8,848,759	18,047,371	24,284,623	4.0	1.9	5.9	
1866-7	3,350,394	25½	10,679,381	9,737,083	6,037,462	15,834,545	24,521,399	3.2	2.0	5.2	
1867-8	3,367,876	21	8,840,675	7,893,459	7,434,337	15,327,796	24,758,437	2.6	2.4	5.0	
1868-9	(3,470,700)	(34½)	(15,021,624)	(14,045,490)	..	..	(24,997,881)	(4.5)	..	..	..
Means 1852-3 to 1867-9	3,538,502	28½	12,644,546	11,650,748	5,249,453	16,900,201	23,003,574	4.1	1.8	5.9	

APPENDIX—TABLE IV.

PARTICULARS OF HOME-PRODUCE, IMPORTS, AND CONSUMPTION OF WHEAT.

IRELAND.

Harvest Years.	ESTIMATED HOME-PRODUCE.			AVAILABLE FOR CONSUMPTION.			AVAILABLE FOR CONSUMPTION PER HEAD.		
	Area under Crop.	Average Yield per Acre.	Total Home-produce.	Home-produce, less 24 Bushels per Acre for Seed.	Imports, less Exports.	Total	Population (middle of Harvest Year).	From Home- produce.	From Imports.
	Acre.	Bushels.	Quarters.	Quarters.	Quarters.	Quarters.		Bushels.	Bushels.
1852-3	353,566	261	1,154,205	1,054,794	781,016	1,835,780	6,244,952	1.4	1.0
1853-4	326,896	271	1,133,585	1,041,645	546,406	1,588,051	6,121,784	1.4	0.7
1854-5	411,284	281	1,452,467	1,336,793	491,552	1,828,345	6,037,505	1.7	0.7
1855-6	445,775	271	1,520,819	1,395,444	553,743	1,949,187	5,986,789	1.9	0.7
1856-7	529,050	241	1,629,963	1,481,167	414,469	1,895,636	5,937,253	2.0	0.6
1857-8	559,646	231	1,662,957	1,505,556	583,151	2,088,707	5,900,361	2.0	0.8
1858-9	546,964	251	1,746,464	1,592,630	990,859	2,573,489	5,871,412	2.2	1.3
1859-60	464,175	251	1,468,475	1,337,925	1,217,300	2,555,225	5,834,544	1.8	1.7
1860-1	466,415	211	1,271,588	1,140,408	1,283,160	2,423,568	5,799,263	1.6	1.8
1861-2	401,243	171	851,871	739,031	1,781,405	2,520,436	5,785,823	1.0	3.5
1862-3	356,321	151	683,048	582,833	1,733,649	2,316,483	5,754,555	0.8	3.2
1863-4	260,311	251	837,906	764,693	1,545,349	2,310,042	5,696,728	1.1	2.2
1864-5	276,483	251	875,782	798,031	1,520,006	2,318,037	5,652,493	1.1	2.2
1865-6	266,989	241	826,783	751,693	1,464,267	2,215,960	5,602,112	1.1	3.2
1866-7	299,190	211	805,710	721,562	1,535,571*	2,257,133	5,565,672	1.0	2.3
1867-8	261,034	231	725,847	652,431	1,581,206*	2,233,637	5,540,627	0.9	2.3
1868-9	(280,112)†	(251)	(879,727)	(800,945)	..	..	(5,515,695)	(1.2)	..
Means 1852-3 to 1867-8	389,084	231	1,165,467	1,056,037	1,125,819	2,181,856	5,838,242	1.4	1.6
									3.0

* No statement of exports found for 1867 or 1868.

† The mean of the Returns for the two preceding years adopted here.

APPENDIX—TABLE V.

PARTICULARS OF HOME-PRODUCE, IMPORTS, AND CONSUMPTION OF WHEAT.

UNITED KINGDOM.*

Harvest Years.	ESTIMATED HOME-PRODUCE.			AVAILABLE FOR CONSUMPTION.			Population (middle of Harvest Year).	AVAILABLE FOR CONSUMPTION PER HEAD.			
	Area under Crop.	Average Yield per Acre.	Total Home-produce.	Home-produce, less 2½ Bushels per Acre for Seed.		Imports, less Exports.		Total.	From Home-produce.	From Imports.	Total.
	Acres.	Bushels.	Quarters.	Quarters.	Quarters.	Quarters.		Bushels.	Bushels.	Bushels.	
1852-3	4,058,731	227	11,574,982	10,433,464	5,902,000	16,335,464	27,511,144	3·0	1·7	4·7	
1853-4	4,013,963	207	10,466,473	9,337,546	6,092,000	15,429,546	27,619,999	2·7	1·8	4·5	
1854-5	4,036,969	324	17,563,140	16,427,742	2,983,000	19,410,742	27,767,398	4·7	0·9	5·6	
1855-6	4,076,447	271	13,922,801	12,776,300	3,265,000	16,041,300	27,947,933	3·7	0·9	4·6	
1856-7	4,213,651	27	14,192,543	13,007,453	4,112,584	17,120,037	28,129,198	3·7	1·2	4·9	
1857-8	4,186,974	331	17,821,221	16,143,915	5,795,687	21,939,602	28,322,607	4·6	1·6	6·2	
1858-9	4,131,822	311	16,309,949	15,147,874	4,565,670	19,703,544	28,623,406	4·2	1·3	5·5	
1859-60	4,019,725	261	13,135,124	12,004,575	4,516,332	16,520,907	28,715,683	3·3	1·3	4·6	
1860-1	3,992,657	221	11,078,948	9,956,012	10,023,968	19,979,980	28,909,045	2·8	2·8	5·6	
1861-2	3,898,177	251	12,271,546	11,175,183	9,099,455	20,274,638	29,128,110	3·1	2·5	5·6	
1862-3	3,823,947	291	13,957,554	12,882,069	9,205,086	22,087,155	29,331,695	3·5	2·5	6·0	
1863-4	3,698,629	381	17,922,048	16,881,807	6,991,270	23,873,077	29,509,228	4·6	1·9	6·5	
1864-5	3,685,493	351	16,216,328	15,179,783	5,500,705	20,680,488	29,700,831	4·1	1·5	5·6	
1865-6	3,646,691	301	13,975,936	12,950,305	7,313,026	20,263,331	29,886,735	3·5	1·9	5·4	
1866-7	3,649,584	261	11,485,091	10,458,645	7,633,033	18,091,678	30,087,001	2·8	2·0	4·8	
1867-8	3,628,910	21	9,566,522	8,545,890	9,015,543	17,561,433	30,299,054	2·3	2·4	4·7	
1868-9	(3,750,812)	(34)	(15,901,351)	(14,816,435)	..	..	(30,513,576)	(3·9)	..	..
Means 1852-3 to 1867-8	3,922,586	28½	13,810,013	12,706,785	6,375,272	19,082,057	28,836,816	3·5	1·8	5·3	

* Exclusive of the Islands in the British Seas.

EXHAUSTION OF THE SOIL,
IN RELATION TO
LANDLORDS' COVENANTS,
AND THE
VALUATION OF
UNEXHAUSTED IMPROVEMENTS.

BY

JOHN BENNET LAWES, Esq., F.R.S., F.C.S.,
OF ROTHAMSTED, HERTS.

READ BEFORE THE LONDON FARMERS' CLUB,
APRIL 4, 1870.

LONDON :
PRINTED BY ROGERSON AND TUXFORD, 265, STRAND, W.C.
1870.

RE-PRINTED BY DUNN & CHIDGEY, 155 & 157, KINGSLAND ROAD, N.E.
1889.

EXHAUSTION OF THE SOIL,

IN RELATION TO

LANDLORDS' COVENANTS,

AND THE

VALUATION OF UXEXHAUSTED

IMPROVEMENTS.

A COMPARISON of the conditions and practice of the agriculture of this country at the commencement of the present century with those which now prevail, brings to view many important changes. Among the more prominent of these is, not only the great improvement in those descriptions of machinery which were then in use, but the introduction and the very general employment of a large number of entirely new machines, adapted to almost every requirement of the farm. Not less characteristic elements of modern advancement and still continued progress are the improvement of our breeds of stock and the use of oilcakes and other purchased cattle-foods, contributing to early maturity and to a greatly increased production of both meat and animal manures ; and lastly, the employment of large quantities of imported, and what are commonly called artificial manures, as distinguished from those which are produced on the farm by the feeding of stock.

Coincident with these changes has been a rise in the value and rent of land ; much greater in the case of the light than in that of the heavier descriptions of soil. As a necessary consequence, too, much more capital has been expended in the cultivation of a given area of land.

It is remarkable however that, with all these important changes of our own time, little or no alteration has taken place either in the actual course of cropping of any district, or in the views which prevail in regard to the necessity of adhering to a fixed rotation of crops. It would seem as if the systems of cropping established by our forefathers were proof against all improvement in spite of the vastly improved means of mechanically working the soil, and the enormous increase in our resources of elements of fertility, in the form of cattle food and manures imported from all quarters of the globe, and of artificial manures manufactured at home.

Nor is it less surprising that, with the extensive and greatly increasing use of expensive purchased cattle foods, the value of which can only be recovered in the meat and manure conjointly, there should be no recognised basis, or general system adopted, for the valuation of unexhausted manures, as between the outgoing tenant on the one hand, and the landlord or the incoming tenant on the other.

As a contribution to the discussion of these important points, I propose to direct your attention this evening chiefly to the following questions :

1. Whether, in order to preserve the soil from exhaustion, it is necessary to enforce a fixed rotation of crops ?
2. What are the best, or most generally applicable means at our disposal, for the estimation of the value of unexhausted manures ?

In considering the characters of soil with the view of arriving at some answer to these questions, it will suffice to confine attention mainly to the definition and illustration of those qualities which are commonly known under the term "*condition*," and to pointing out the distinction between these and those which are due to what may be called the *normal* or *natural fertility* of the land. There are other points of great practical and scientific interest in connection with the state of fertility of our soils which must be left out of view on this occasion ; as, for instance, the influence of the various crops we cultivate, the special

effects of ordinary and of various artificial manures, the loss of fertilizing matters by drainage, and allied subjects.

The word "condition" is in very common use amongst agriculturists. It is said that a farm is "in condition," or "out of condition," or in "high condition," or in "low condition." These terms are well understood to imply certain states of fertility which it is not easy to define more accurately in a few words. As I understand it, the word "condition" refers to those elements of fertility in a soil which, whether they have been accumulated by natural processes or by the art of the farmer, are capable of being turned to account in the growth of crops within a limited period of time, and which by such growth are soon exhausted. "Condition" is, therefore, something altogether distinct from the natural or standard fertility of the soil. A soil may be naturally very fertile, but at the same time very much out of condition; or it may be naturally very poor, but in very high condition.

As an illustration of a soil brought into a state of high condition by natural causes, I will quote a few sentences from that great writer on the science and practice of agriculture, M. Boussingault. In his *Rural Economy*, p. 231, he says:

"By far the finest crops of Indian corn in America are obtained upon breaks of virgin soil. I do not hesitate to say that the husbandman gains from six hundred to seven hundred times his seed under such circumstances. The mode of proceeding upon these breaks, which I have frequently witnessed, deserves to fix attention for a moment.

"The planter chooses the end of the rainy season for cutting down the trees and the brushwood; everything remains where it falls until it is sufficiently dry; fire is then set to the heap, and the burning extends and lasts even for weeks; all the smaller branches are completely consumed, nothing but the charred trunks of the larger trees remain. As the rainy season is about to return, a man with a pointed stick in his hand, goes over the burnt surface, making a hole of no great depth at intervals, into which he throws two or three particles of Indian corn, over which he draws a little earth, or rather ashes, by a slight motion of his foot. This

primitive mode of sowing terminated, the planter takes no further heed of the crop; his habitation is often so remote, that he never visits it until harvest time; the rain and the climate do all the work: it is unnecessary to hoe, the burning having destroyed all the plants that were indigenous to the soil, nothing rises but the grain which has been sown. In such fields stems of Indian corn are frequently seen of the height of from twelve to fourteen feet. It rarely happens that more than three consecutive crops are taken from the burnt soil; and the last, though still very superior to anything which we can obtain by our regular husbandry, is not to compare with the first. As there is no want of forest, it is held preferable to make a fresh break."

Here, then, we have an instance of a soil in which the elements of productiveness, having been gradually accumulating for ages, are so far exhausted by three successive crops of Indian corn, as to render it more profitable to abandon the land, and clear a fresh portion of the forest, than to cultivate the same area over again.

As a more familiar instance of land brought into "condition" by somewhat similar causes, may be mentioned old pasture, when broken up and converted into arable land.

The cases of land brought into "condition" which it is much more to our present purpose to consider are, however, those in which the immediate productiveness is due directly to the outlay of capital by the tenant, by the use of purchased foods and manures, by means of which the land is brought for a longer or shorter, but still only for a limited period, into an increased state of productiveness.

By way of special illustration of such "condition" I will direct attention to some results selected from among those of the numerous field experiments made on my farm at Rothamsted.

Table 1 shows the produce of dressed corn per acre, on certain plots of a field which has now grown wheat year after year for more than a quarter of a century. Up to the autumn of 1843 it was under the ordinary system of cultivation of the farm. In 1839 it was dunged, and grew turnips; in the next four years it was unmanured; growing barley in 1840, peas in 1841, wheat in 1842, and oats in 1843. In the autumn of 1843 the first experi-

mental wheat crop was sown, and the twenty-seventh is now growing. Portions of the field have received no manure whatever during the whole period of the experiments; one portion has been manured with fourteen tons of farm-yard dung every year; and the remainder, divided into numerous plots, has been manured with different descriptions of artificial manure, the same description having, as a rule, been applied to the same plot year after year for the last eighteen years, and in some cases for longer still.

Table 2 shows the results of experiments in which barley has been grown year after year in an adjoining field for many years in succession, the nineteenth crop being now in the ground. The plan of manuring has been very similar to that in the wheat field; portions being always unmanured, part being annually manured with farm-yard dung, and the remainder divided into plots, which have been manured, respectively, with different descriptions of artificial manure.

Table 3 relates to experiments on the four-course rotation of turnips, barley, clover or beans, and wheat; and therefore illustrates "condition" of soil under circumstances much more nearly representing the ordinary practices of agriculture than when corn crops are grown year after year on the same land. The twenty-third crop—that is to say, the third crop of the sixth-course—is now growing. The root-crop, commencing each course has been liberally manured with mineral manure, ammonia-salts, and rape-cake; both roots and tops have been carted off the land, and the three following crops of each course grown without any further manuring. Clover was the third crop in the first course; but as it will not grow once in four years, beans have been substituted for it in the succeeding courses. The Table gives the average produce, respectively, of turnips (roots and tops), barley, beans, and wheat, over the second, third, fourth, and fifth courses—that is to say, over the four complete rotations in which beans were grown.

Table 4 gives the results of experiments conducted for fourteen years in succession on permanent meadow land, the plan of manuring having been much the same as in the case of the experiments on wheat and barley.

EXHAUSTION OF THE SOIL,
ILLUSTRATIONS OF CONDITION.

TABLE 1.

Wheat grown year after year on the same land.

Years.	PLOT 2.	PLOT 16.	PLOT 5.	PLOT 17. PLOT 18.	
	14 tons Dung, every year ; 26 Years, 1844-69.	Mixed mineral Manure, and 800 lbs. Ammonia Salts ; 13 Years, 1852-64	Mixed mineral Manure alone ; 18 Years, 1852-69.	Mixed mineral Manure and Ammonia Salts. alternated ; 18 Years, 1852-1869.	
	Bushels of Dressed Corn per Acre.	Bushels of Dressed Corn per Acre.	Bushels of Dressed Corn per Acre.	Bushels of Dressed Corn per Acre.	Bushels of Dressed Corn per Acre.
1844	20½	19½	15½	18½	20½
1845	32	32½	24½	32½	33
1846	27½	27	25	32	26½
1847	29½	32	30½	34½	30½
1848	25½	30½	30½	28½	26½
1849	31	33½	38½	33½	32½
1850	28½	33½	30½	30½	29½
1851	29½	36½	37	31½	31
Average .	—	30½	29½	30½	28½
8 years, 1844-51					
1852	27½	28½	*16½	†24½	*14½
1853	19½	25½	*10½	* 8½	†19½
1854	41½	49½	*24½	†44½	*23½
1855	34½	32½	*18½	* 18	†39½
1856	36½	37½	*19½	†31	*17½
1857	41½	49½	*23½	*26½	†40½
1858	38½	41½	*18½	†33½	*21½
1859	36½	34½	*20½	*20½	†32½
1860	32½	32½	*15½	†25½	*15½
1861	34½	37	*15½	*18½	†32½
1862	38½	36½	*17½	†27½	*18½
1863	44	55½	*19½	*21½	†46½
1864	40	51½	*16½	†36½	*17½
1865	37½	32½	*14½	*17	†31½
1866	32½	17½	*13½	†26½	*12½
1867	27½	14½	* 9½	*10½	†23½
1868	41½	22½	*17½	†37½	*18½
1869	38½	16½	*15½	*16½	†22½
AVERAGES :					
26 years, 1844-69	33½	—	—	—	—
21 years, 1844-64	—	36½	—	—	—
13 years, 1852-64	—	39½	—	—	—
5 years, 1865-69	—	20½	—	—	—
18 years, 1852-69	—	—	—	†24½	†24½
18 years, 1852-69	—	—	*17½	*17½	†31½

* Mineral manure. † Ammonia Salts. ‡ Mineral manure and Ammonia Salts.

ILLUSTRATIONS OF CONDITION.

TABLE 2.

Barley grown year after year on the same land.

	PLOT 7.	PLOT 2A	PLOT 2AA.
Years.	14 Tons Dung every year ; 18 Years, 1852-1869.	Superphosphate and 200 lbs. Ammonia Salts every year ; 18 Years, 1852-1869.	Superphosphate, and 400 lbs. Ammonia Salts, 6 Years ; 200 lbs. Ammonia Salts, 10 Years ; 275 lbs. Nitrate, 2 Years. Total, 18 Years : 1852-1869.
	Bushels of Dressed Corn per Acre.	Bushels of Dressed Corn per Acre	Bushels of Dressed Corn per Acre.
1852	33	38½	43½
1853	36½	40½	42½
1854	56½	60½	63½
1855	50½	47½	50½
1856	32½	29½	31½
1857	51½	56½	66½
1858	55	51½	56½
1859	40	34½	35½
1860	41½	43½	43½
1861	54½	55	55½
1862	49½	48½	51
1863	59½	61½	60½
1864	62	58½	56½
1865	52½	48½	47½
1866	53½	50½	50½
1867	45½	44	44½
1868	43½	37½	44
1869	46½	48	48½
AVERAGES:			
18 years, 1852- '69	48	47½	—
6 years, 1852- '57	—	45½	49½

ILLUSTRATIONS OF CONDITION.

TABLE 3.

*Artificially Manured Four-course Rotation, conducted through 5½ Courses,**(22 Years,) 1848-1869.**Average Produce of the 2nd, 3rd, 4th, and 5th Courses (16 Years) 1852-1867.*

Years.	Description of Crop.	Mixed mineral Manure, Ammonia Salts, and Rapecake, for Turnips only, of each Course; 1852, 1856, 1860, 1864. Turnips carted off.
1852, 1856, 1860, 1864 ...	Swedish Turnips*	Per Acre. 13 tons 3½ cwts.
1853, 1857, 1861, 1865 ...	Barley	48½ bushels.
1854, 1858, 1862, 1866 ...	Beans	21½ "
1855, 1859, 1863, 1867 ...	Wheat	36½ "

* Roots and tops.

ILLUSTRATIONS OF CONDITION.

TABLE 4.

Experiments with Manures on Permanent Meadow Land.

Years.	PLOT 2.		PLOT 9.
	14 Tons Dung, 8 Years, 1856-'63 ; Unmanured, 6 Years, 1864-'69. Total 14 Years, 1856-1869.		Mixed Mineral Manure, and 400 lbs. Ammonia Salts, every year ; 14 Years, 1856-1869.
	Hay per Acre. Cwts.		Hay per Acre. Cwts.
1856	...	36	56½
1857	...	47½	57½
1858	...	57½	64
1859	...	40½	55½
1860	...	46½	50½
1861	...	45½	56½
1862	...	45½	57½
1863	...	44½	53½
1864	...	48½	50½
1865	...	25½	34½
1866	...	43	44½
1867	...	51	48
1868	...	36½	59½
1869	...	55½	68½
AVERAGES :			
8 years, 1856-'63	...	42½	—
6 years, 1864-'69	...	43½	—
14 years, 1856-'69	...	43	54

I will first call attention generally to the fact that, throughout the long periods over which these various experiments have extended, "*condition*" has been equally kept up whether farm-yard dung, or certain chemical mixtures, were employed.

In the wheat experiments, the average of 26 successive crops grown by farm-yard dung was $33\frac{3}{4}$ bushels; the average on plot 16, of 21 crops grown by artificial manure was $36\frac{1}{8}$ bushels, and the average on the same plot, over 13 years when the artificial manures were increased in quantity, was $39\frac{1}{2}$ bushels. In the case of the barley, the average over 18 years of farm-yard dung was 48 bushels, and over 18 years of artificial manures $47\frac{1}{2}$ bushels. In the rotation experiment, after the removal, on the average of the four courses, of about $13\frac{1}{4}$ tons of turnips, which had been manured with artificial manure, the average of the four crops of barley was $48\frac{5}{8}$ bushels, and that of the four crops of wheat $36\frac{3}{4}$ bushels. Lastly, in the 14 years' experiments on permanent meadow land, the average produce of hay where farm-yard manure was employed, was 43 cwts., and where artificial manures were used 54 cwts. It is obvious, therefore, as I have already said, that land can be kept in "*condition*," whether continually under grain crops, under rotation, or growing natural grasses, equally by farm-yard dung or artificial manures.

I will now endeavour to illustrate the extent, or limit, of duration of "*condition*" of soil, under different circumstances of manuring.

I will refer first to the experiments on wheat, the results of which are given in Table 1. During the first eight years, from 1844 to 1851 inclusive, plot 16 was variously manured with mineral manure and ammonia-salts, and gave an average annual produce of $30\frac{3}{4}$ bushels. During the next 13 years, from 1852 to 1864 inclusive, it received every year a mineral manure, composed of salts of potass, soda, and magnesia, and superphosphate of lime, and also a largely increased amount of ammonia-salts, namely 800 lbs. per acre per annum, and the average produce over the 13 years was $39\frac{1}{2}$ bushels. The manuring was then stopped, so that the crops of 1865 and since, have been entirely unmanured. The crop of 1865, the first after the cessation of the manuring, was

32½ bushels, the second 17½, the third 14½, the fourth 22½, and the fifth 16½ bushels. It is obvious, therefore, that the "condition" of the land, due to the unexhausted residue of the manures applied during the 21 previous years, was sufficient to yield a fair crop in the first year after the manuring was stopped, but that the produce then rapidly declined.

It should be stated, however, that the quantity of ammonia applied in this experiment was very excessive, amounting, in the 21 years, to as much as would be supplied in 10 tons of Peruvian guano. Deducting the amount of nitrogen in the increase of crop in the 21 years, from the amount supplied in the manure during the same period, it appeared that nitrogen equal to more than a ton of ammonia, and to more than would be supplied in 6½ tons of Peruvian guano, remained unrecovered in the increase of crop. An analysis of the soil to the depth of 27 inches from the surface showed that about one-third of this excess still remained in the soil within that depth, at that period; leaving, however, the remaining two-thirds still unaccounted for. Even the one-third retained within a depth of 27 inches from the surface would appear, from the small produce yielded by it, to be so diffused, and locked up in such states of combination in the soil, as to be available in very small quantities annually. Of the remaining two-thirds, doubtless a part is still retained in the soil below a depth of 27 inches; but probably the largest proportion of it has passed off, in the form of nitric acid, in the drainage-water.

In the other experiments on wheat, the results of which are given in the Table, the amounts of ammonia applied were by no means so excessive, only half as much being annually applied where they were used at all, as during the 13 years of excessive application on plot 16. During the first eight years of the 26, that is from 1844 to 1851 inclusive, plots 5, 17, and 18, were manured with various, but, upon the whole, somewhat similar mixtures of mineral manure, ammonia-salts, and sometimes rape-cake, and gave nearly equal average amounts of produce over the eight years, namely—29½, 30½, and 28½ bushels, respectively.

From that date, 1852, to the present time, a period of 18 years, plot 5 has been manured, every year, with a mixed mineral manure

containing salts of potass, soda, and magnesia, and superphosphate of lime ; and every year during the same period plots 17 and 18 have been manured with the same mineral manure, or ammonia-salts, alternately. For example, in 1852 plot 17 received ammonia-salts, and plot 18 the mineral manure. In 1853 plot 17 received the mineral manure, and plot 18 the ammonia-salts, and so on, alternately for the 18 years ; thus, plots 17 and 18 have each been manured nine times with ammonia-salts and nine times with the mineral manure during the 18 years, the difference being that when one received ammonia-salts the other received mineral manure, and *vice versa* ; and, accordingly, we have had each year one plot manured with mineral manure following a residue of ammonia-salts, and one plot manured with ammonia-salts following a residue of mineral manure.

Over the 18 years the average produce of plots 17 and 18 was exactly the same, namely— $24\frac{5}{8}$ bushels in each case ; but if we take the average of the 18 crops grown by mineral manure alone, whether upon plots 17 or 18, we find it to be only $17\frac{3}{4}$ bushels, whilst the average of the 18 crops grown on either plot by ammonia-salts is $31\frac{5}{8}$ bushels, or nearly 14 bushels per acre per annum more. At the time of the commencement of this set of experiments the utility of supplying ammonia as manure for grain crops was vehemently disputed, it being asserted that if only a sufficiency of available mineral constituents were provided within the soil, the plant would obtain all the necessary ammonia from the atmosphere. It would hardly be possible to select, or arrange, a set of experiments more entirely conclusive against such a view. The mineral manures, though always succeeding upon a residue of ammonia-salts, gave only a small crop, whilst the ammonia-salts, succeeding upon a residue of mineral manure which had been useless without them, gave a large crop.

My present object is not, however, to show the effects of one manure compared with another, but to ascertain how far the un-exhausted residue from previous manuring affects the produce of succeeding crops. Plot 5, manured *every year* with the mineral manure alone, gave an average over the 18 years of $17\frac{1}{2}$ bushels, whilst the same mineral manures applied on either plot 17 or 18,

and always after a residue of ammonia-salts, gave only $17\frac{3}{4}$ bushels, or less than $\frac{3}{4}$ bushel per acre per annum of increase due to the unexhausted residue of the previously applied ammonia-salts, these being employed in comparatively moderate quantity.

From these results it is clear, that the soil may be kept in "condition" to yield a fair crop of wheat every year, by the application of ammonia-salts and certain mineral manures; but, that, if the ammonia-salts be only applied in moderate quantity, the unexhausted residue will very little affect the produce of succeeding crops.

I will now refer to Table 2, which gives some results of experiments on the growth of barley for eighteen years in succession on the same land. Plot 2A has been manured every year with superphosphate of lime and ammonia-salts; and plot 2AA has received the same amount of superphosphate every year, and twice as much ammonia during the first six years, but only the same amount as plot 2A each year since. Taking the six years, of the double application of ammonia on plot 2AA, the result is an average of $49\frac{1}{2}$ bushels, against only $45\frac{1}{2}$ on plot 2A, with the smaller amount of ammonia-salts, thus showing an average increase of four bushels per acre per annum due to the extra amount of ammonia-salts applied. In 1858, the first year in which the amount of ammonia applied on plot 2AA was reduced to the same as that on plot 2A, it still gave five bushels more than the latter; in the next year it gave only $1\frac{1}{2}$ bushel more; and in the third year the produce was practically equal on the two plots. Here again, then, the unexhausted residue from the ammonia-salts previously applied has appreciably increased the succeeding crop; but it should be stated that the amount of ammonia-salts—400lbs. per acre per annum—applied during the previous six years was, for barley, very large, indeed excessive.

Table 3 gives the average produce over four consecutive four-course rotations, in which the turnips were liberally manured with mineral manure, ammonia-salts, and rapecake, and the whole crop (roots and tops) carted from the land. On the average, about $13\frac{1}{4}$ tons of turnips were removed; yet it will be seen that the un-

exhausted residue from the manures applied for the turnip crop was such that an average produce over the four courses of 48½ bushels of barley, 21½ bushels of beans, and 36½ bushels of wheat, was obtained.

In the experiments on permanent meadow land, the results of which are given in Table 4, plot 2 was manured with 14 tons of farmyard dung per acre per annum for the first eight years, and has since (that is for six years) been left entirely unmanured. It will be seen that during the eight years of the application of dung the average annual produce of hay was a little under 43 cwts., and that during the six following years it amounted, without any further application of manure, to a little over 43 cwts., of hay, thus showing a very marked effect from the unexhausted residue of the previous heavy dressings of farmyard dung.

From the above results, relating to wheat, barley, rotation, and permanent meadow, the following conclusions may be drawn :

1. That *condition* of land may be maintained, either by farmyard manure or by artificial manures.
 2. That when active nitrogenous manures, such as Peruvian guano, ammonia-salts, or nitrate of soda, are applied in only the moderate quantities usually employed in practical agriculture, the unexhausted residue left in the soil after the removal of a corn crop has but little effect on succeeding crops.
 3. That when rapeseed, bones, and other purchased organic manures, which yield up their fertilizing elements comparatively slowly, are employed, the unexhausted residue left after the removal of the first crop may yield an appreciable amount of increase throughout a rotation.
 4. That when farmyard dung is employed, the effects may be apparent for a still longer period.
 5. That when mineral manures, such as phosphates, salts of potash, &c., are used, the effects of any unexhausted residue are too slow and gradual to admit of any determination of their value.
- So far, I have endeavoured by means of some actual experimental results to illustrate "condition" of soil; and it is obvious

that when it results from the expenditure of capital in the purchase of cattle food or direct manures, it should be reckoned as the property of the tenant.

I now propose to consider certain other characters of soil which are not included under the term "condition."

When a tenant takes a farm, what is it he agrees to pay rent for? Partly for the use of a residence and farm buildings; but the greater portion of the rent is paid for permission to grow crops on the land. The course of cropping is either expressly stipulated in the lease or agreement, or the tenant is bound by the "custom of the country." As he is subject to penalties if he deviate from the course so prescribed, it must be assumed, either that that course is the very best he could follow for his own interest and profit, or that by following any other, with a view to increased profit to himself, the interest of the owner would be sacrificed, by a reduction of the *natural or standard fertility*, or rent-value, of the land.

Admitting that the recognised rotation of any district may be, upon the whole, the most suitable to follow in it, it nevertheless will not be denied that the farmer of intelligence and capital would, if he were permitted to do so, occasionally deviate from it with profit to himself at any rate. It will be well, therefore, to direct attention to some results illustrative of the extent and limit of the productive capability of a soil of a certain class or character, with a view of forming some judgement of the probability of injury to the land by a deviation from the ordinary course of cropping. I have, in the course of my various experiments, sought to gauge the capability of my soil to yield crops for many years in succession without manure, and even under more exhausting conditions still, and some of the results obtained are recorded in Table 5. It should be stated, however, that in no case has any attempt been made to increase the productiveness by either subsoiling or deeper ploughing than usual, though great care has been taken to keep the land as free from weeds as possible without injury to the crop by treading.

ILLUSTRATIONS OF NATURAL FERTILITY.

TABLE 5.

Experiments with Wheat, Barley, and Meadow-hay.

Years.	Wheat.		Barley.	Meadow-hay.
	PLOT 3. Unmanured every year ; 26 Years, 1844-1869.	PLOT 10A. Ammonia Salts, alone ; 25 Years, 1845-1869.	PLOT 10. Unmanured every year ; 18 Years, 1852-1869.	PLOT 3. Unmanured every year ; 14 Years, 1856-1869.
	Bushels.	Bushels.	Bushels.	Cwts.
1844	15	15½	—	—
1845	23½	31½	—	—
1846	17½	27½	—	—
1847	16½	25½	—	—
1848	14½	19½	—	—
1849	19½	32½	—	—
1850	15½	26½	—	—
1851	15½	28½	—	—
1852	13½	21½	27½	—
1853	5½	9½	25½	—
1854	21½	34½	35	—
1855	17	19½	31	—
1856	14½	24½	13½	22½
1857	19½	29½	26½	25½
1858	18	22½	21½	22
1859	18½	18½	13½	22½
1860	12½	15½	13½	24½
1861	11½	12½	16½	25½
1862	16	23	16½	27½
1863	17½	39½	22½	20½
1864	16½	32	24	24
1865	13½	25½	18	11½
1866	12½	26½	15½	23½
1867	8½	18½	17½	29½
1868	16½	24½	10½	17½
1869	14½	20½	15½	18
AVERAGES :				
First Period ...	16½	25½	23	24½
Second " ...	15	23½	17½	23½
Total " ...	15½	24½	20½	23½
AVERAGE STRAW, PER ACRE—CWTN.				
First Period ...	15½	25½	13½	—
Second " ...	12½	21½	10½	—
Total " ...	14	24	12½	—

The first column of the Table shows the produce of wheat obtained for 26 years in succession, from 1844 to 1869 inclusive, on a portion of the experimental wheat-field which has received no manure whatever since 1839. The average produce, per acre per annum, over the 26 years, has been rather over $15\frac{1}{2}$ bushels of dressed corn, about 14 cwts. of straw, and $22\frac{3}{4}$ cwts. of total produce (corn and straw together). The average over the second half of the period is $1\frac{1}{2}$ bushel of corn, and $2\frac{3}{4}$ cwts. of straw, less than over the first half; showing perhaps a slight, but at any rate no very marked, tendency to decline in annual yield.

I hold in my hand a specimen of this unmanured produce grown in 1868, the 25th crop of wheat in succession, and the 29th crop since the application of any manure to the land. Here also is a section of the soil, taken to the depth of 30 inches; and, so far as can be judged from appearance, certainly no one of experience in such matters would take it to be naturally more fertile than the majority of moderately heavy soils in this country. Nor does the rent of similar land in the neighbourhood (25s. to 30s. per acre tithe free), or the condition of the farmers of the district as to wealth, indicate any great fertility of the soil.

On plot 10A, the productive capabilities of this same soil have been still further put to the test; and the results enable us not only to gauge the past, but to form some idea of its prospective productiveness.

For the crop of 1844, the first of the experimental series, this plot received a dressing of superphosphate of lime and silicate of potass; but not any, either potass, soda, lime, magnesia, phosphoric acid, or silica, has been applied since that date. For the crop of 1845, and for each crop since, that is for 25 years in succession, it has been manured with ammonia-salts alone. During that period it has given an average annual produce of $24\frac{3}{8}$ bushels of dressed corn, and 24 cwts. of straw per acre, per annum, being an average annual increase over the unmanured produce of $8\frac{3}{4}$ bushels of corn, and $9\frac{1}{2}$ cwts. of straw, and a total increase over the 25 years of nearly 220 bushels of corn, and $289\frac{1}{8}$ cwts. (nearly 12 tons) of straw.

It is obvious from these results, that the soil of this plot 10A has yielded up annually, for this long period, considerably more mineral matter from its own resources than the unmanured plot. There is however, an average annual produce of $1\frac{3}{8}$ bushel of corn, and $3\frac{7}{8}$ cwts. of straw, less over the last 18 than over the previous 12 years

of the period. Assuming this to be due to exhaustion, and not to difference of seasons only—and there is the evidence of analysis that it is at least in a great measure due to exhaustion—it is still obvious that it would take many more years yet to bring down the annual yield of this plot to that of the unmanured one.

The next column in the Table shows the amounts of produce of barley obtained for 18 years in succession on the same land, without any manure, in an immediately adjoining field. The average produce over the whole period is $20\frac{1}{2}$ bushels of corn, and $12\frac{1}{2}$ cwt. of straw, per acre per annum. There is, however, a considerable reduction of produce in the later years; the average of the first 9 years being 23 bushels of corn and $13\frac{5}{8}$ cwt. of straw, and of the second 9 years only $17\frac{3}{8}$ bushels of corn and $10\frac{5}{8}$ cwt. of straw, or a reduction of $5\frac{5}{8}$ bushels of corn and 3 cwt. of straw, per acre per annum, over the second half of the period as compared with the first. This more rapid reduction in the case of barley than of wheat is doubtless due to the much more limited range of the roots of barley, so that in its case an actually less bulk of soil has contributed to the crop, and the exhaustion, though telling more upon the crop, is, therefore, more superficial than in the case of wheat.

The permanent meadow-land gave, over 14 years, an average of $23\frac{1}{2}$ cwt. of hay per acre per annum without manure, and, as the figures show, an average of only $\frac{3}{4}$ cwt. less over the second than over the first half of the period.

ILLUSTRATIONS OF NATURAL FERTILITY.

TABLE 6.

Unmanured Four-Course Rotation, conducted through 5½ courses (22 years), 1848-1869.

Average Produce of the 2nd, 3rd, 4th, and 5th courses (16 years), 1852-1867.

Years.	Description of Crop.	Unmanured, every year; sixteen years, 1852 — 1867. Turnips carted off.
		Per Acre.
1852, 1856, 1860, 1864 ...	Swedish Turnips *	$18\frac{1}{2}$ Cwts.
1853, 1857, 1861, 1865 ...	Barley	$40\frac{1}{2}$ bushels.
1854, 1858, 1862, 1866 ...	Beans	$12\frac{1}{2}$ "
1855, 1859, 1863, 1867 ...	Wheat	$34\frac{1}{2}$ "

* Roots and tops.

Lastly, as Table 6 shows, the 2nd, 3rd, 4th, and 5th courses of five consecutive entirely unmanured four-course rotations, gave scarcely any turnips at all ; but the average of the four crops of barley was $40\frac{1}{2}$ bushels, of the four crops of beans $12\frac{1}{2}$ bushels, and of the four crops of wheat $34\frac{1}{2}$ bushels.

To sum up the chief points of these illustrations of the extent, or limit, of the fertility of a somewhat heavy loam, of by no means extraordinary quality, it has yielded an average annual produce, without any manure at all, of $15\frac{1}{2}$ bushels of wheat for twenty-six years, of $20\frac{1}{2}$ bushels of barley for eighteen years, of $23\frac{1}{2}$ cwt. of hay for fourteen years, and, under rotation for twenty years, an average over the last four courses, or sixteen years, of $40\frac{1}{2}$ bushels of barley, $12\frac{1}{2}$ bushels of beans, and $34\frac{1}{2}$ bushels of wheat.

I confess that my view of the productive capability of heavy, or even moderately heavy soils, has undergone considerable change since I commenced the various experiments to which I have referred. Formerly I supposed that a very few years of consecutive corn-growing would suffice to reduce the corn-growing capabilities of any ordinary soil to practically nothing. Such, however, is not the case ; and a very little reflection will show how essential it is for the well-being, if not, indeed, for the existence of man, that the elements of fertility should be so locked up and distributed throughout the soil, as to be capable of being taken up by crops extremely gradually, and so to last for an immense period of time. If needy landlords, or indigent tenants, could have drawn upon the locked up elements upon which the maintenance of the natural or standard fertility of the soil depends, how little fertile soil would still remain in England !

It has sometimes been argued that the soil is to be looked upon as little else than a support for plants, to which the cultivator must add all the constituents necessary for the growth of the crops he removes ; just as the manufacturer who hires a mill has to supply the cotton or other material for the manufacture. I think, however, it would be difficult to account for the difference of rent paid for land, except on the assumption that it yields, from its own resources, a greater or less surplus, in the forms of corn and meat, beyond the amounts required to pay the cost of cultivation, to return interest on capital employed, and to afford a

profit to the tenant. I think, further, observation will show that, excepting in the case of the lighter soils under modern management, the rent-value of different descriptions of land has generally borne a closer proportion to their relative natural fertility than to any other circumstance.

Let us suppose, for example, three descriptions of soil : one that would yield 5, another 15, and another 25 bushels of wheat per acre, from their own unaided resources ; that is, without the use of any purchased cattle food or manure. A soil which would yield only 5 bushels of wheat would probably bear no rent at all, the whole value of the produce being required to meet the costs of cultivation. The soil yielding 15 bushels would doubtless pay a rent, and the one yielding 25 bushels a considerably higher rent. But now let us assume that all three cultivators were able to go into the market and purchase cattle food and manure : the three soils would be very differently affected by this importation of elements of fertility from without. An amount of money expended in food and manure that would raise the produce on the poorest soil from 5 bushels to 25, would not raise that on the medium soil from 15 to 35 bushels, and still less would it increase the yield on the best soil from 25 to 45 bushels of wheat. It is obvious, therefore, that the surplus available for rent, dependent on such an use of elements of fertility from without, would be proportionally the greatest on the poorest soil, and the least upon the naturally most productive soil.

It is chiefly in the fact here illustrated, that is to be found an explanation of the rapid rise in the rent of light soils of late years. Compared with heavy land, they are cultivated at a less cost, they are much better adapted to carry stock, and with the aid of purchased food and manures they can now rival in productiveness the natural fertility of clays and loams. So long as the farmer depended almost exclusively upon the natural fertility of the soil, the surplus to pay rent was much less on those light soils which could supply from their own resources but little of the constituents required for the growth of crops ; but since he has been able to go into the market and purchase, in the form of cattle food and direct manures, those elements of which his soil was deficient, the increase of productiveness which has followed has, as a matter of fact,

been found to be proportionally much the greater in the case of the lighter and naturally less fertile, than in that of the heavier and more fertile soils. Thus, the productiveness of light soils is in a greater degree dependent on the amount of capital expended on food and manure, than is that of the heavier soils. Moreover, the increased fertility and the increased rent of the lighter soils of late years, are partly due to the accumulations from the past expenditure of the tenant. This increased productiveness is, however, of the character of improved "condition;" and hence it is that the productiveness of such soils may be comparatively easily and rapidly reduced.

That, excepting in the case of light soils under the conditions above referred to, the amount of rent paid is, in practice, chiefly dependent on the natural fertility of the soil, and not on the amount of capital employed by the tenant, is evident from the fact that there are, on many estates, highly cultivated farms with abundance of capital invested, adjoining others in a very opposite condition; the poor farmer being able to set apart from the produce of the land as large a surplus in the form of rent as his higher farming neighbour; whilst any demand for an increase of rent on account of increased capital employed, would be met with the remonstrance that the benefits arising from the increased expenditure of capital by the tenant should justly accrue to himself.

From the facts and arguments which have been adduced in regard to the *natural fertility* of the heavier soils, and to the essential conditions of productiveness of the lighter soils, the question naturally suggests itself—whether, or under what circumstances, the more frequent growth of corn than accords with the recognised rotation of a district might be permitted without risk of deteriorating the property of the landlord? Although any such repetition of corn-crops is strongly objected to, as tending to exhaust the soil, it is remarkable that many operations which affect the soil in an exactly similar way are not only allowed, but approved. A fallow, for example, is an economical means of obtaining the produce of two seasons in one year; certain costs of cultivation, seed, and harvesting, are saved; but so far as the removal of constituents from the soil is concerned, it is immaterial whether two crops of wheat of 16 bushels, or one of 32 bushels, be taken from the land. By liming, again, certain constituents which are locked up in the soil are set free and rendered available much more rapidly, and so

are removed in larger quantity within a limited period of time than they otherwise would be. The same result, namely, the export from the farm of larger crops within a limited period of time, follows in like manner from the use of the subsoil plough, the steam smasher, and a great variety of implements of modern application. In fact, all these processes, which are regarded with favour rather than otherwise, have the one object and result of causing the soil to yield up its elements of fertility more rapidly.

I believe that whilst a greater freedom from the adoption of a fixed rotation would often be beneficial to the tenant, it would not, if accompanied with proper conditions, result in any injury to the landlord. In saying this, I trust it will not for a moment be supposed that I would recommend the abandonment of a rotation of crops, and the continuous growth of corn. To be more specific, what I do think is, that where fallow, or liming, or subsoiling, or steam smashing, and allied processes, are admissible and advantageous, or where root crops cannot be consumed on the land during wet weather without injury to the succeeding crops—that is to say on the heavier and deeper soils—barley may often be grown both in larger quantity and better in quality after wheat than after a root crop. Again, where mangolds are manured, as they often are, with 20 or even 30 tons of dung per acre, I see no objection, either from a scientific or practical point of view, in taking out of the land the large quantity of mineral constituents still remaining available after the removal of the mangolds, by growing two or even three corn crops in succession, with the application of artificial manure for each extra crop. Very generally, indeed, two corn crops might be taken in succession from medium and heavy land, provided it be kept free from weeds, and artificial manures be applied for the second crop. Nor do I think that real injury would be done by the occasional growth of peas, or even an extra corn crop, on light soils, when the seeds have failed, as occurred after the dry summer of 1868; indeed, as much of some fertilizing matters might be washed out of the soil by drainage as would be exported from the land in the extra crop.

So far I have endeavoured to illustrate what is "*condition*," and

to point out the distinction between it and what may be called the *natural fertility*, of a soil. I have maintained that "condition" is a quality dependent on the expenditure of the tenant, and that it should be considered as a part of his capital. I have also shown that "condition" may be withdrawn, or reduced, by cropping, within a very limited period of time. "Natural fertility," on the other hand, is the property of the landlord; and although it is not absolutely inexhaustible, it is very little liable to injury from any system of agriculture which, so far as present appearances enable us to judge, has any prospect of prevailing in this country.

It remains to offer some suggestions of a practical kind, with a view to the protection of the landlord, or succeeding tenant, from injury, in case of any considerable modification, or the entire removal, of the usual restrictions in regard to cropping; and also as to the best, or simplest, method of estimating the value of the unexhausted capital of the outgoing tenant, with a view to compensation from the landlord or the incoming tenant.

It will be admitted on all hands, that if the tenant were unconditionally free as to his course of cropping, and he were to leave his farm wholly under corn, the landlord would not so readily obtain a tenant for the farm. I would propose, therefore :

1. That all land should be given up with a fixed proportion under fallow, root-crops, seeds, and corn-crops; the proportions to be settled according to the custom of the locality; and that the outgoing tenant should pay a compensation, to be assessed by competent valuers, for any excess of land under corn over the so fixed amount.

2. That, excepting under special arrangement, and with the purchase of stable-dung, or similar town manures, no straw or root crops shall be sold off the farm.

3. That the tenant should be required to keep the land free from weeds; and, in default, to pay compensation to the landlord or incoming tenant for the cost of cleaning; such cost to be assessed by competent persons.

The cost of cleaning foul land which is in high condition is much greater than that of putting land which is poor in condition, but free from weeds, into good condition. Moreover, the state of the land as to weeds should be one important element in deciding whether an extra corn crop should or should not be taken. If, therefore, the tenant be allowed greater latitude in regard to cropping, more stringent clauses should be inserted in agreements against foul land.

However highly a tenant may farm during the early or middle years of his occupation, he, as a rule, endeavours as far as possible to withdraw his capital out of the land, by reducing its *condition* towards the end of his term, lest neither the landlord nor the incoming tenant should adequately compensate him for his unexhausted manures.

It must be admitted that there is great difficulty in laying down any rules which shall be generally applicable for the estimation of the productive, and consequently the money, value of the residue of manures which have previously been applied to the soil, and have already yielded a crop. It has been shown by reference to direct results, that some important constituents of manure either leave little or no unexhausted residue in the land, or leave it so combined within the soil, or so distributed throughout it, that it produces little or no appreciable effect on succeeding crops. Some manures, on the other hand, have been shown to produce marked effects for several years after their application. It is obvious, therefore, that it would require a very complicated sliding-scale to enable us to estimate the value of unexhausted manures under the many varying conditions that would arise—as to the description and amount employed, the soil, the season, and the crop grown—were it attempted to take as a basis the valuation of constituents already under ground. In Lincolnshire, and adjoining counties, half-inch bones are valued to the incoming tenant the second year after application, and in some instances guano is valued after it has grown a crop. It would, I think, be much more satisfactory that all valuation should, if possible, relate only to what is above ground. Nor do I see any difficulty in doing full justice to the out-going tenant without taking into account the value of the unexhausted residue of manures which have already yielded a crop.

The three items upon which I would rely as the basis of a valuation in favour of the outgoing tenant are—the farmyard manure made during the last year of the occupancy; the manure from purchased food which has not grown a crop; and the straw of the corn crops of the last harvest.

The quantity of straw grown is a pretty sure indication of the condition of the land in regard to recent manuring. To take an extreme case by way of illustration: the continuously unmanured wheat plot, which has been already referred to, gave an average of only about 14 cwts. of straw per acre, whilst plot 16 gave, over the thirteen years of heavy manuring, $46\frac{1}{2}$ cwts., or 3 1-3rd times as much. Now, if I had entered upon a farm with the straw of the corn crops given over to me not exceeding 14 cwts. per acre, and left it with straw averaging 3 1-3rd times as much, I might surely in justice claim, of the landlord or my successor, compensation for such an increase in the quantity of straw, indicating as it would the increased condition of the land. In reference to this point, it may further be remarked, in passing, that not more than about 5 per cent. of the weight of the straw is derived from the constituents of the soil itself, by far the greater part being derived from the atmosphere, through the agency of the manures applied, and directly due, therefore, to the expenditure of the tenant's capital.

I propose, then, as a part of the compensation to the improving outgoing tenant, that he shall be paid the consuming value of the straw which he leaves in excess of that which he entered upon.

The next point to consider is, the valuation of the manure which has been obtained by the consumption of purchased cattle food within twelve months from the termination of the occupation, and which has not yet yielded a crop.

Some years ago, I published a Table showing the calculated value of the manure resulting from the consumption of 1 ton of each of the chief standard articles of cattle food. Those estimates were, at the time, considered by some to be somewhat too high. They have lately been carefully re-considered; and, taking into account the higher money value of some of the chief constituents at the present time, it has been decided to make but little further alteration than to add a few articles to the list that were not previously included in it. The results are given in Table 7.

TABLE 7.

Estimated Value of the Manure obtained by the Consumption of different Articles of Food, each supposed to be of good quality of its kind.

Description of Food.	Money Value of the Manure from one Ton of each Food.
	£ s. d.
1. Cotton-seed Cake, decorticated	6 10 0
2. Rapecake	4 18 6
3. Linseed Cake	4 12 6
4. Cotton-seed Cake, not decorticated	3 18 6
5. Lentils	3 17 0
6. Beans	3 14 0
7. Tares	3 13 6
8. Linseed	3 13 0
9. Peas	3 2 6
10. Indian Meal	1 11 0
11. Locust Beans	1 2 6
12. Malt-dust	4 5 6
13. Bran	2 18 0
14. Coarse Pollard	2 18 0
15. Fine Pollard	2 17 0
16. Oats	1 15 0
17. Wheat	1 13 0
18. Malt	1 11 6
19. Barley	1 10 0
20. Clover Hay	2 5 6
21. Meadow Hay	1 10 6
22. Bean Straw	1 0 6
23. Pea Straw	0 18 9
24. Oat Straw	0 13 6
25. Wheat Straw	0 12 6
26. Barley Straw	0 10 9
27. Potatoes	0 7 0
28. Parsnips	0 5 6
29. Mangold-wurtzel	0 5 3
30. Swedish Turnips	0 4 3
31. Common Turnips	0 4 0
32. Carrots	0 4 0

It will be observed how very widely different is the estimated money value of the manure obtained by the consumption of one ton of different articles of cattle-food in common use. It is ob-

vious, therefore, that, in settling the amount of compensation to be paid to the outgoing tenant for the value of the manure produced by the consumption of purchased food, it would not suffice to take a fixed proportion of the purchased-food bill, but the value of the manure-constituents of the particular description of food actually employed must be estimated. It would no more be fair to make the valuation irrespectively of the value of the constituents obtained from the different descriptions of food, than it would be to charge the same price for the inferior descriptions of guano as for the best Peruvian.

As the value of the constituents obtained as manure from one ton of the various foods has been estimated at their market price, if sold in a concentrated, dry, and easily-portable state, some reduction from the amounts given in the Table should be made in the valuation supposed, on account of the risk of loss by decomposition and drainage, and for the extra cost of carriage and application to the field, all of which will be greater in the case of the cattle manure than in that of the dry purchased manure. For these reasons I would propose that one-third, or one-fourth, less than the amounts shown in the Table should be allowed for all purchased cattle-food used within twelve months of the termination of the occupation, provided the manure obtained from it has not yet grown a crop.

It is, I believe, the custom in Norfolk, and in some other counties, for the tenant going out at Michaelmas to apply the dung made during the previous winter to the root crop, the incoming tenant taking the crop at a valuation. The objections to this plan are, that the root crop is a very uncertain one, and may, in a bad season, be very much less than the amount of manure should produce: and that if the outgoing tenant has fed his stock upon purchased food, the value of the manure cannot be recovered in the root-crop alone, even if the season be favourable. For example, in one of the courses of experimental rotation to which I have referred, after a liberal manuring of rape-cake, salts of ammonia, and mineral manure, less than $4\frac{1}{2}$ tons of roots were removed; and the result was, that the succeeding crops amounted, without any further manure, to $60\frac{1}{2}$ bushels of barley, $48\frac{1}{2}$ bushels of beans, and 46 bushels of wheat. It is obvious that, under the system referred

to, these heavy crops of barley, beans, and wheat, would become the property of the incoming tenant, whilst he would only have to pay for the manure which had largely contributed to produce them, the small value of $4\frac{1}{2}$ tons of roots.

I would submit that it would be a much fairer arrangement to value the manure made during the winter by the load, or ton, and that the incoming tenant should also pay two-thirds, or three-fourths, the estimated money value of the manure from the purchased food consumed in its production. If, in addition to this, the out-going tenant were paid the consuming value of the straw of the corn crops of the last harvest, he would receive fair compensation for the capital which he had invested in "*condition*," whilst the incoming tenant would only have to pay for that which possessed an actual money value.

The conclusions arrived at in the course of the foregoing discussion may be briefly summarised as follows :

1. "*Condition*" is a quality quite distinct from *natural fertility* of soil : it is mainly dependent on the amount of capital expended by the tenant in the purchase of cattle-food or manures, and is, therefore, his property ; it may be easily and rapidly reduced.

2. The *natural fertility* of a soil, whether high or low in degree, is, comparatively speaking, a permanent quality ; it can only be injuriously affected by the continuance of an exhaustive system of cropping for a long period of time ; it is the property of the landlord ; and, excepting in the case of very light soils, it is the chief element in determining the rent-value of the land.

3. In the case at any rate of the heavier soils, it would generally be beneficial to the tenant of capital and intelligence, if he were allowed much more freedom as to cropping than present customs permit.

4. No injury is likely to result to the landlord from granting the tenant permission to crop as he pleases, provided he be bound to keep the land free from weeds, and to leave a fixed proportion under fallow and green crops, at the termination of his occupation.

5. No simple rules, applicable to various descriptions of soil, season, crop, and manure, can be laid down for the valuation of the unexhausted residue of previously applied manures which have already yielded a crop.

6. By the valuation of so much of the farm-yard manure, and of so much of the manure-constituents derived from purchased cattle food, as have not yet yielded a crop, and also of the straw of the last harvest, fair compensation may be made to the outgoing tenant, whilst the in-coming tenant will only be required to pay for that which has a fixed and easily-ascertainable money-value.

In 1845 the late Mr. Ph. Pusey made the following remarks in an article in the *Journal* of the Royal Agricultural Society of England (Vol. V.): "The subject of unexhausted improvements seems to me the most important of all agricultural subjects for landlords at present, and the improvement of our agreements in this respect to be a condition *sine quâ non* of any steady and general improvement of the soil or its cultivation."

If this were true then, how much more is it so now! During the quarter of a century which has elapsed since these lines were written, very great advances have been made in British agriculture, and every step in the progress has been accompanied with an increased outlay of money. If abundant capital is to be attracted to the soil, it is essential that liberal covenants in regard to cropping should be adopted, and fair compensation for unexhausted improvements made. If I have this evening in any degree contributed to that advancement of knowledge which is necessary before we can hope to attain marked improvement in these respects, I shall feel that I have not occupied your time in vain.

Printed by Rogerson & Tuxford, 285, Strand, London.
1870.

Re-Printed by Dunn & Chidgey, 156-7, Kingsland Road, N.E.
1889.

SCIENTIFIC AGRICULTURE

WITH A

VIEW TO PROFIT.

BY

JOHN BENNET LAWES, ESQ., F.R.S., F.C.S.

OF ROTHAMSTED, HERTS.

READ BEFORE THE MAIDSTONE FARMERS' CLUB,

DECEMBER 15, 1870.

MAIDSTONE:
SOUTH EASTERN GAZETTE OFFICE, WEEK STREET.

1870.

LONDON:
RE-PRINTED BY DUNN & CHIDGEY, 165-7, KINGSLAND ROAD, N.E.

1889.

Scientific Agriculture with a View to Profit.

"Practice with Science," the motto of the Royal Agricultural Society of England, and "Scientific Agriculture with a view to Profit," the title of the subject we are to discuss this evening, represent very similar ideas. It is true, the founders of the Society gave more prominence to "Practice," by placing that word before "Science;" while the committee of the Maidstone Farmers' Club have given to Science the place of honour; but they have indicated, in plain and unmistakable language, upon what terms they yield the position of distinction to Science—it is only provided it can be followed "with a view to profit." They say in fact to science—"fill our stack-yards, and our pockets, and you are welcome; but do not trouble us with abstract truths, or speculative opinions, which we cannot turn to profitable account."

I think I may assume that your desire to discuss this subject, and my presence here to introduce it, are due in great measure to what some of the members of this Club saw and heard on the occasion of a visit which I had the honour to receive from them, at Rothamsted, during the past summer. They then saw, as many others have seen, that a great deal of active investigation has been, and still is, going on there in connection with agriculture; and I have little doubt they felt some disappointment, as I know others have done, at not being able to see very clearly the direct practical lessons to be learnt from the results of so much labour. If their thoughts were put into words they would probably say—"you have made very interesting experiments on various crops, both with ordinary and with artificial manures; you have conducted numerous experiments on the feeding of stock; and you have a laboratory contain-

ing nearly 20,000 bottles ; but we wish you to understand that we take no special interest in these things, excepting so far as they relate to our business. We are farmers ; our capital is invested in the cultivation of the soil ; and the welfare of ourselves and of our families depends upon the profits we can realize. We want to know—how, if you were a farmer, with no other source of income, you would use your knowledge to increase your profits ? or rather—how, if in addition to our practical knowledge we possessed all the information which you have acquired from your scientific experiments, should we alter our practice to increase our profits ? ” I take it that, in arranging for this evening’s discussion, the Maidstone Farmers’ Club hoped, by its means, to arrive at some solution of the above questions.

When we consider that the system of agriculture practised by the most intelligent farmers of any district, has been the result of long observation and experience, it must be admitted that any important changes suggested by science should, as far as possible, be based on a knowledge of the principles involved in the existing practices. For example, those who would propose to interfere with the ordinary course of rotation, by substituting a corn-crop for a pulse or a root-crop, may reasonably be asked, not only—what description and amount of manure will be required to grow the corn crop ? but also—what will be the relative state of fertility in which the land will be left when the one crop has been substituted for the other ? Again, if it be proposed to use artificial manures, instead of producing ordinary manure by the feeding of stock on cake or other purchased food, it is obviously desirable to possess accurate knowledge—not only as to the description and amount of artificial manure required to produce a given crop, but also as to the amount of meat, and the amount and composition of the manure, that will be yielded by the different descriptions of purchased food.

Now, I propose to show you, by one or two examples, how much labour, and how much money, the investigation of subjects having a direct bearing on the practice and profits of agriculture may require, before absolute certainty can be arrived at respecting them ; and I could, without difficulty, occupy the whole of the time of this meeting in pointing out the various subjects which have been, and still require to be, investigated by men of science, before long established existing practices can be thoroughly explained.

I dare say most of you know that the atmosphere which we breathe is composed almost entirely of a mixture of nitrogen and oxygen. The nitrogen constitutes more than three-fourths of the whole by weight, and the quantity of it resting upon every acre of our fields, amounts to more than 32,300 tons. All the crops we grow contain nitrogen, some in larger and some in smaller quantity. Nitrogen is, also, as you well know, a very active and a very expensive element in manures, costing when purchased in artificial manure not much less than one shilling per lb. Accurate knowledge in connection with this substance is, therefore, of the greatest possible interest to the farmer.

As all our crops are so dependent upon nitrogen in their food, and as they are surrounded by so large a store of it in the atmosphere throughout their growth, what could be more natural than to suppose that they obtain it from that source? What investigation could be more important than to determine whether they are able to do so or not? and, if they are, to settle to what extent they do so, or by which of them, or under what circumstances, the largest quantity of it can be assimilated. In fact, one of the explanations which has been put forward of the benefits to be derived from a rotation of crops is, that whilst some plants can absorb the nitrogen of the atmosphere, others cannot do so. Here, then, is a question for scientific investigation "with a view to profit;" and what do we find has been done to arrive at a solution of it?

Nearly a century ago, Priestley and Ingenhousz came to one conclusion on the subject from their experiments, and Sennebie and Woodhouse to an opposite one from theirs. About the end of the last century and the beginning of the present one, De Saussure took up the question; and, a little more than thirty years ago, Boussingault, one of the most laborious and accurate of living chemists who have devoted themselves to agricultural subjects, commenced the enquiry, and renewed it from time to time, for a period of about twenty years, he arriving at one conclusion, and M. G. Ville, another French chemist, who worked at the subject for many years, coming to an opposite conclusion. Besides these, minor investigations have been undertaken by Mène, Roy, Cloez and Gratiolet, De Luca, Harting, and Chlebodarow and Petzholdt, with considerably varying results. Lastly, the field and other experiments at Rothamsted having shown how important was a

definite settlement of this question, and, considering how conflicting was the existing evidence bearing upon it, the investigation was undertaken there, and a very intelligent young American Chemist, the late Dr. Pugh, was engaged upon the subject, at the Rothamsted Laboratory, for nearly three years. Well, the result of all this expenditure of time and money, extending over a period of more than three-quarters of a century, is a balance of evidence in favour of the view that the free nitrogen of the atmosphere cannot be assimilated by our crops.

One more illustration, and I have done with this part of my subject. It may be taken as an established fact, that if the price of the hay, cake or corn, and roots, which the farmer gives to his oxen and sheep, or of the meal which he gives to his pigs, be charged against the animal, the cost of the food will be more than the increased value in the shape of meat. To show a profit upon the feeding transaction, it is necessary to charge a portion of the cost of the food against the manure obtained. It is, however, quite possible to keep land in high condition for growing corn, without the manure produced by feeding stock. Whether it will be the more advantageous to attain the end by the production of meat and of animal manure, or by the use of artificial manures, is entirely a question of cost, depending on the character of the land, the prices of meat and corn, and the relative cost of certain constituents in cattle manure, and in artificial manures. But, obviously essential elements in the enquiry are—what proportion of the various constituents of the purchased cattle food will be obtained in the form of meat?—what proportion will be expended or lost by the respiration and perspiration of the animal?—and how much will remain as manure?

Let me put a case to illustrate the point in question. 1 cwt. of rape-cake will cost six shillings, and 1 cwt. of linseed-cake about twice as much. If applied at once to the soil, these two substances would be of very nearly the same value as manure. Both would supply about 8lbs. of mineral matter, and about 90lbs of organic matter, containing nitrogen equal to about $6\frac{1}{2}$ lbs. of ammonia. But the linseed-cake is first employed for the feeding of stock, and the questions arise—how much of the above constituents will go to form increase? how much will be expended or lost by the vital processes of the animal? and how much will remain for manure? Now,

these points can only be settled by very laborious scientific investigation. I could give you a long list of the names of those who have experimented upon one or other branch of the enquiry ; and the subject, in one or other of its aspects, has been under experiment at Rothamsted, from time to time, for more than twenty years. Well, it may perhaps safely be assumed that, of the total dry or solid matter of the linseed-cake, not more than 10 per cent., and of its total nitrogen not more than 5 per cent., will be retained by the animal as increase. Of the total solid matter, however, a large proportion will be expended by the respiration of the animal ; leaving, in fact, only about 25 or 30 per cent. of the whole as manure. But the essential point whether, besides the small proportion of the nitrogen of the food which is stored up in the increase of the animal, another portion is expended and lost by respiration and perspiration, or whether the whole of that which is not retained by the animal remains for manure, can hardly be said to be absolutely settled. The balance of the evidence is, however, in favour of the view that there is no loss of the nitrogen of the food excepting that which contributes to the increase of the animal, and that which may be due to the decomposition of the manure after the animal has produced it.

I have brought forward these illustrations to show you how much time, labour, and money, must be expended in scientific enquiry, before some of the most fundamental practices of agriculture can be thoroughly understood ; and before, therefore the £ s. d. standard of calculation can be rigidly applied to them. Whilst, however, much remains to be done before we can discuss some important branches of the science of agriculture " with a view to profit," we can, I think, in the mean time, learn much from the results of field experiments, if conducted on a sufficiently large scale, for a sufficient length of time, and with due regard to accuracy. I believe the experiments at Rothamsted meet these requirements ; and I now propose to consider how far the results of some of them are applicable to agriculture " with a view to profit."

Among the results of the Rothamsted field-experiments there is one fact which stands out with the greatest possible prominence ; viz., that certain substances, which constitute a very small proportion of the crops, exert a very striking influence on their growth when employed as manures. Thus, nitrogen, in the form of ammonia-salts, or

nitrate of soda, used in admixture with superphosphate of lime, and applied to the Rothamsted soil when in an agricultural sense in a state of exhaustion—that is when it is unfit to grow another grain-crop without manure—will yield a full crop of corn; and with a repetition of the manure each year, will continue to do so for many years in succession.

For example, a mixture of 300lbs. of superphosphate of lime, and 200lbs. of ammonia-salts, applied every year for nineteen years, has yielded almost exactly the same amount of barley as 300lbs. of superphosphate of lime and 1,000lbs. of rape-cake, or as fourteen tons of dung, applied annually for the same period. Each of the three has given an average of about forty-eight bushels, or six quarters of barley, and about 28cwts. of straw. Nitrate of soda has not been used in similar combination for so long a period; but it may be assumed, that if, instead of the 200lbs. of ammonia-salts, 275lbs. of nitrate of soda had been employed every year with the superphosphate of lime, almost identically the same result would have been obtained.

Now, let us compare the quantity of certain constituents in forty-eight bushels of barley, and its straw, with that of the same constituents contained in the above-named different kinds of manure which will produce it. The following table illustrates the point.

	Dry Organic matter.	Mineral matter.	Nitro- gen.
	lbs.	lbs.	lbs.
6 Qrs. barley and 28cwts. straw	4566	196	56
14 Tons farm-yard manure	8640	868	200
1000 lbs. Rape-cake	810	80	50
200 lbs. Ammonia-salts .....	..	..	41
275 lbs. Nitrate of soda .....	..	..	41

Thus, of dry organic matter the crop would contain about 4,566 lbs., or rather more than two tons. Of such substance the annual dressing of dung would supply nearly twice as much, and the rape-cake not one-fifth as much as the crop contained; whilst the ammonia-salts, or nitrate of soda, would supply none at all. Of mineral matter, again, the dung would annually supply very much more, and the rape-cake very much less than the crop contained. Of nitrogen, too, the dung would contain from three to four times as much as the crop; whilst neither the rape-cake, the ammonia-salts, nor the nitrate, would contain as much as the crop. Practi-

cally, then, we obtain the same quantity of corn and straw whether we supply much more or much less organic matter than the crop contains, or even none at all. In fact, more than 90 per cent. of the really dry substance of the crop may be derived, either directly or indirectly, from the air and water, and not from the substance of the soil itself, or of the manure.

A similar result is brought out even more strikingly in the experiments on the continuous growth of wheat. To one plot in the experimental wheat field, 14 tons of farm-yard dung per acre have been applied annually for 27 years in succession; but the amount of produce yielded by it is exceeded by that from mixtures of mineral and nitrogenous manure, supplying no organic matter whatever. It may be considered established, then, that, at any rate in the case of moderately heavy soil such as that at Rothamsted, the only manures required for the production of good corn crops for a number of years in succession, are such as will supply certain mineral constituents, and nitrogen, the latter either in the form of ammonia-salts, or nitrate of soda.

Referring again to the results with the barley, I wish to recall your attention prominently to the fact, that the 14 tons of farm-yard manure, which gave only the same amount of produce as the mixture of superphosphate of lime and ammonia-salts, or superphosphate of lime and nitrate of soda, not only supplied large quantities of organic and mineral constituents of which the artificial mixtures contained none, but it also supplied probably between four and five times as much nitrogen as either of the artificial mixtures, and yet only gave the same amount of crop. The salts of ammonia supplied 41lbs. of nitrogen in the form of ammonia; the nitrate of soda also 41lbs. in the form of nitric acid; and, for some years, an amount of ammonia-salts containing 82lbs. of nitrogen was applied to one series of plots, but this was found to be too much, the crop generally being too heavy, and laid. Yet, probably about 200lbs. of nitrogen was annually supplied in the dung, but with it there was no over-luxuriance, and no more crop than where 41lbs. of nitrogen was supplied in the form of ammonia or nitric acid. How is this to be accounted for?

The answer to this question must be, that the activity of vegetation does not depend alone upon the mere amount of the required

constituents provided within the soil ; but very materially also on the state of their combination, and distribution, being such that they can be taken up by the growing plants. Only a comparatively small proportion of the nitrogen of the dung exists as ready-formed ammonia, and the remainder only very gradually passes into that state of combination. Hence it is that dung is found to be what is considered by some so desirable—namely, a lasting manure ; that is to say, a manure which only yields up its fertilising constituents very slowly. Salts of ammonia and nitrate of soda are, on the other hand, both very soluble in water ; but, when applied as manure, the ammonia of the ammonia-salts is much more readily absorbed and retained by the soil than is the nitric acid of the nitrate. The latter, consequently, distributes more rapidly, and is more liable to be dissolved by heavy rains, and washed into the drains, or the sub-soil ; though a portion of the ammonia of the ammonia-salts itself becomes converted into nitric acid, and then is subject, in like manner, to loss by drainage.

The farmer has, therefore, to deal with that very important constituent of manure—*nitrogen*—in very different conditions of combination, in which it acts very differently when applied to the soil. It is probable that when the re-actions of these various descriptions of nitrogenous manure on different descriptions of soil have been more carefully investigated, and are better understood, some considerable saving may be effected in their use. At Rothamsted, in the experiments on wheat less, and in those on barley not much more, than half of the nitrogen supplied as ammonia-salts or nitrate of soda is recovered as *increase* of produce in the first crop ; and only from *one-sixth* to *one-fifth* of that which is supplied in the form of dung is so recovered. Our attention is now directed to this subject, and experiments are in progress to determine whether a reduced amount of these valuable manures will not yield an equal result, if applied more carefully in close proximity to the growing plant.

Taking, however, the Rothamsted experiments as they stand, let us now examine—what results they give when brought to the standard of profit and loss ? In the barley field the average annual produce obtained by the annual application of 300lbs. of superphosphate of lime, and 200lbs. of salts of ammonia, or instead 275lbs. of nitrate of soda, has been, as already stated, about 6 quarters, or 48

bushels of dressed corn, and 28cwts. of straw. As the supply of nitrate of soda in the market is much greater than that of the ammonia-salts, I will adopt the nitrate as the basis of calculation. We have then the cost of the crop per acre, approximately as follows:—

	£	s.	d.
275lbs., or say 2½cwts., nitrate of soda, at 16s.	2	0	0
2½cwts. superphosphate of lime, at 5s.	0	13	9
Sowing Manure	0	1	6
Rent, tithe, and rates	1	15	0
Ploughing	0	10	0
Scarifying	0	3	0
Harrowing	0	4	0
Rolling.....	0	2	0
Drilling.....	0	2	0
3 bushels seed, at 4s. 3d.	0	12	9
Hoing and Weeding	0	7	0
Harvesting	0	10	0
Thrashing and dressing, at 2s. per quarter	0	12	0
	£7	13	0

The above may be considered as a close approximation to what would be the annual cost of growing a crop of barley for a number of years in succession, at Rothamsted.

On the other side of the account we have—

	£	s.	d.
6 quarters of dressed barley, at £1 16s. per quarter	10	16	0
3 bushels of offal barley, at 2s. 6d.	0	7	6
28cwts. of straw, at 1s.	1	8	0
	12	11	6
Cost of the crop	7	13	0
Profit per acre.....	£4	18	6

I will next call your attention to a few of the experiments on the continuous growth of wheat. The first crop of the series was harvested in 1844, and the 28th in succession is now growing. Omitting the results of the first eight years—1844 to 1851 inclusive—when the manures were not exactly the same as they have been since, we have, as in the case of the barley, a period of 19 years—1852 to 1870 inclusive—during which the same manures have been applied to the same plots year after year. Plot 5 has received each year a mixture of salts of potass, soda, and magnesia, and superphosphate of lime; Plot 6 the same mineral manures as Plot 5, with 200lbs. of ammonia-salts per acre; Plot 7 the same mineral manures, and 400lbs. of ammonia-salts per acre; and Plot 9 the same mineral manures, and 550lbs. of nitrate of soda per acre.

The following are the average results over the 19 years :—

Plots.	Per Acre, per Annum ; 19 years, 1852-1870.		
	Manures.	Aver. Produce	
		Dressed Corn.	Straw
		Bush.	Cwts.
5	Mixed Mineral Manure, alone	17	15
6	Ditto, Ditto, and 200lbs. am. salts	27	25
7	Ditto, Ditto, and 400lbs. am. salts	36	36
9	Ditto, Ditto, and 550lbs. nit. soda	37	41
2	14 Tons Farm-yard dung	36	34

Thus, the mixed mineral manures alone give, over 19 years, an average annual produce of wheat, of 17 bushels of corn, and 15cwts. of straw, per acre. The addition of 200lbs. of ammonia-salts per acre to the mineral manures gives an increase of 10 bushels of corn, and 10cwts. of straw ; the addition of 400lbs. of ammonia-salts to the mineral manures gives an increase of 19 bushels of corn, and 21cwts. of straw ; and the addition of 550lbs. of nitrate of soda to the mineral manures gives an increase of 20 bushels of corn, and 26cwts. of straw. The farm-yard dung, on the other hand, gives the same amount of corn, but 2cwts. less straw than the mineral manures and 400lbs. of ammonia-salts; and 1 bushel less corn, and 7cwts. less straw, than the mineral manures and 550lbs. of nitrate of soda.

It is evident from these results that, in the case of moderately heavy land like that of the experimental field at Rothamsted, full crops of wheat may be grown for many years in succession, by means of the annual application of certain mineral constituents, with ammonia-salts, or nitrate of soda, in addition.

Taking, again, the cost and result with nitrate of soda as the basis of calculation, the following will be the money account per acre of the experiment on the continuous growth of wheat.

	\$	s.	d.
550lbs., or say 5cwts., nitrate of soda, at 16s.....	4	0	0
Salts of potass. soda, and magnesia	2	10	0
2½ cwts. superphosphate of lime, at 5s.	0	13	9
Sowing manure	0	1	6
Rent, tithe, and rates	1	15	0
Ploughing	0	10	0
Scarifying	0	3	0
Harrowing	0	4	0
Rolling.....	0	2	0
Drilling	0	2	0
2 bushels seed, at 6s.....	0	12	0
Hoing and weeding.....	1	0	0
Harvesting	1	0	0
Thrashing and dressing, at 2s. per quarter	0	9	3

£13 2 6

On the other side of the account we have—

	£	s.	d.
37 bushels of dressed wheat, at 6s.....	11	2	0
2½ bushels of offal corn, at 2s.....	0	5	0
41 cwts. of straw, at 20s. per load (1,296lbs.).....	3	10	10
	14	17	10
Cost of the crop.....	13	2	6
Profit per acre.....	£1	15	4

There are several reasons why the results with the wheat are not so satisfactory as those with the barley in point of profit. The crop is much more costly to keep clean ; and, as you will see, I have charged seven shillings for hoeing an acre of barley, but twenty shillings for hoeing and cleaning an acre of wheat. Again, for a given weight of corn, there is nearly one-and-a-half time as much wheat straw as barley straw ; and with the winter-sown and stronger straw crop, we are enabled, in the average of seasons, to ripen a greater weight of total produce. The result is, that, to obtain a full crop of wheat, we have to employ about twice as much ammonia-salts, or nitrate of soda, as is required to yield what may be called a corresponding crop of barley. Thus, 48 bushels of barley, and 36 or 37 bushels of wheat, may be taken as of nearly equal money value ; but to grow 48 bushels of barley we have used only 200lbs. of ammonia-salts, or 275lbs. of nitrate of soda, producing at the same time only 28cwts. of straw ; whereas to get 36 or 37 bushels of wheat, we used 400lbs. of ammonia-salts, or 550 lbs. nitrate of soda, and produced about two tons of straw ; withdrawing, of course, at the same time, much more mineral matter from the soil.

It is obvious that, in growing wheat or barley year after year by the manures above described, and removing both corn and straw from the land, the exhaustion of mineral constituents will show itself sooner in the case of wheat than in that of barley. Hence it is that, in the wheat account given above, there is the heavy charge of 50s. for salts of potass, soda, and magnesia ; whilst there is no such charge against the barley crop. The amount of those salts annually used in the particular experiments quoted was, it is true, considerably more than would be required to compensate for the exhaustion by the increase of crop obtained. It must be distinctly borne in mind, however, that the Rothamsted experiments are not arranged with a view to providing direct examples of profit.

At the same time, the fact is clearly brought out, that more money must be expended on nitrogenous manures to yield a given money-value in wheat-grain, than an equal value in barley-grain. Calculations show, indeed, that, of a given amount of the expensive constituent nitrogen supplied in manure, a larger proportion is taken up from the soil by the barley than by the wheat crop.

To conclude, in regard to the wheat experiments, I am sure you will agree with me that the fact of having removed 27 full crops in succession from the same land, is one of the greatest possible interest and importance, as showing what constituents must, and what need not, be applied to the soil for the successful growth of the crop. But, although the growth of wheat under such circumstances may require the employment, as manure, of expensive constituents, such as potass, it is by no means to be concluded that such manures would be requisite under the very much modified application of the system of more frequent corn growing, which could alone be followed in farming "with a view to profit."

As the experiments on the continuous growth of oats, at Rothamsted, have as yet only extended over two seasons, I will not occupy your time by following up the illustration as to profit in regard to that crop. The land devoted to the experiments was dunged for beans in 1864; it then grew wheat in 1865; beans in 1866, and wheat in 1867 and 1868, all without manure: and the first experimental oat-crop was taken in 1869. In regard to the results, it will suffice to say, that the same mixture of superphosphate of lime, salts of the alkalies, and ammonia-salts, or nitrate of soda, as was employed for the wheat (on plots 7 and 9 respectively), gave, in the favourable season of 1869, about 70 bushels of oats, and about 50cwts. of straw, and in the unfavourable one of 1870, about 50 bushels of oats, and 28½cwts. of straw.

I will now direct your attention to some experiments on rotation. In one field at Rothamsted an experiment on rotation of crops has now been carried on for nearly 24 years. The course followed is—turnips; barley; clover, beans, or fallow; and wheat. On one portion the swedes are very highly manured, with a mixture of rape-cake, salts of ammonia, superphosphate of lime, and salts of potass, soda, and magnesia. From one half of this piece the whole of the swedes, both roots and tops, are carted off; and on the other half the crop is consumed on the land by sheep. The 24th crop, that is the

last of the sixth course, is now growing. Omitting the first course, in which Norfolk whites and clover were grown, and the sixth, which is not yet completed, the following are the quantities of roots, and of dressed corn, per acre, obtained in the second, third, fourth, and fifth courses.

Crop, &c.		Swedes Carted off the Land.	Swedes Consumed on Land.
3rd COURSE.			
1852.....	Swedes	19½ Tons.	19½ Tons.
1853.....	Barley	38½ Bushels.	35½ Bushels.
1854.....	Beans	10 "	13 "
1855.....	Wheat	37½ "	40½ "
3rd COURSE.			
1856.....	Swedes	16½ Tons.	17 Tons.
1857.....	Barley	48 Bushels.	63½ Bushels.
1858.....	Beans	12½ "	14½ "
1859.....	Wheat	39½ "	38½ "
4th COURSE.			
1860.....	Swedes	4½ Tons.	3½ Tons.
1861.....	Barley	60½ Bushels.	54½ Bushels.
1862.....	Beans	43½ "	41½ "
1863.....	Wheat	46½ "	44½ "
5th COURSE.			
1864.....	Swedes	8½ Tons.	8½ Tons.
1865.....	Barley	47½ Bushels.	43½ Bushels.
1866.....	Beans	20½ "	24½ "
1867.....	Wheat	23½ "	21½ "
SUMMARY—AVERAGE OF THE FOUR COURSES.			
1852, '56, '60, '64 ..	Swedes	12½ Tons.	12 Tons.
1853, '57, '61, '65 ..	Barley	48½ Bushels.	49 Bushels.
1854, '58, '62, '66 ..	Beans	21½ "	23½ "
1855, '59, '63, '67 ..	Wheat	36½ "	38½ "

Thus, the average produce of swedes was about 12 tons of roots, and there were besides about $\frac{3}{4}$ ton of tops. The manures applied to each crop of turnips, if they had been employed directly for barley, would have been sufficient to grow three crops of about 6 quarters each; that is, in all, 18 quarters of barley. Yet, we find that the average yield of the rotation where the whole of the roots were consumed on the land, was almost exactly the same as where they had been carted off. The condition of these two plots must, however, have been very different. The amount of nitrogen alone, returned to the land by the stock consuming the turnip crop, would probably

be equal to that contained in between 400 and 500lbs. of nitrate of soda.

From the results of these experiments we may learn :—

1. That the growth of the root-crop did not of itself contribute anything to the fertility of the land.
2. That the treading of the land by the stock was injurious to the succeeding barley-crop.
3. That it is not alone the quantity of manurial constituents applied, which determines the amount of the crop ; but that the effect depends very much upon the condition in which the constituents exist within the soil.

A careful consideration of these results, and also of those of experiments in which swedes have been grown year after year for many years in succession on the same land, leads me to the conclusion, that on the heavier class of soils, where the treading of sheep is injurious, the turnip crop, if not out of place, might at all events with advantage occupy a much less proportion of the area of the farm than it usually does. There are many and obvious reasons why it would be impracticable to devote the whole of the arable land of a farm to the growth of corn ; and if I were farming with a view to profit alone, I should not attempt to do so. But, taking as a basis the facts that, on moderately heavy, and heavy land, full crops of wheat, barley, or oats, may be grown with certainty for some years in succession, by means of artificial manures containing soluble phosphate, and nitrogen in the form of ammonia or nitric acid, and that the increased produce obtained by these manures is remunerative, I should certainly devote a much larger proportion of my land to corn than is usual in the district. To give an example of what I have done in this direction, I may mention that a field adjoining the experimental barley field, received a heavy dressing of dung and artificial manure for mangolds in 1866, and since then it has grown wheat, oats, barley, and barley, in succession. The last two crops of barley have each been fully seven quarters per acre ; and another corn crop is to be taken from the land in the coming season.

I am also disposed to give up the growth of turnips altogether ; growing no other roots but mangolds, and these probably to the extent of not more than 1-15th or 1-20th of the arable land of the

farm. Under this system the land for the mangolds should be manured very heavily with dung, applied partly in the autumn and partly in the spring, and also with artificial manure at the time of sowing. It would be advisable, too, to prepare the land for the spring corn as much as possible in the autumn, by means of steam ; and, of course, altogether to avoid injury by treading with sheep in wet weather. To what extent such a system would be applicable and profitable in other districts must be left in great measure to the judgment of the individual farmer to decide.

In the " Report on the Farm-Prize Competition, 1870," published in the last number of the *Journal of the Royal Agricultural Society of England*, Mr. Keary condemns the system of growing more frequent corn crops, by the use of artificial manures. On the other hand, in the *Agricultural Gazette*, for November 5, and November 19, we have an account of the successful cultivation of a farm on which 330 to 350 acres of grain are grown out of a total area of 450. The whole produce, corn and straw, is sold off the farm ; no stock is kept ; and no meat is produced. There can be no difficulty whatever in agreeing with Mr. Keary in doubting whether, upon light soils, where the treading of sheep is beneficial, " the alternation of green and white crops can properly be departed from ; " and, for my part, I do not recommend that it should be on such soils, unless under very special circumstances. I equally agree with Mr. Prout, that on soils of quite another description, both roots and stock may be more plague than profit ; and, in fact, that, by means of steam, or other deep cultivation, and the judicious employment of those special fertilisers which experience shows to be advantageous, remunerative corn-crops can be grown over a larger area of the farm than is consistent with our recognised systems of rotation. Cleanliness is, however, an essential element in the profitable growth of corn ; and when the land becomes foul, the corn growing should be suspended, and a fallow or cleaning crop taken.

The time is past for maintaining a servile adherence to fixed systems of rotation as essential to profitable agriculture, whatever the description of the land, the intelligence of the farmer, or the local conditions of his farm. Whether we look to the greatly extended knowledge of the present cultivators of the soil, to the greatly increased command of the elements of fertility in the form of purchased cattle foods and manures, to the marvellous develop-

ment of mechanical appliances, or to the increased facilities for transit and for the carriage of produce, it must be admitted that the farmer of the present day, as compared with his predecessors, has very marked advantages. And it is only reasonable to suppose, that these great changes should have a commensurate influence in modifying systems and practices which owe their origin, and their reason, to other times and to other circumstances.

In conclusion : if those who farm "with a view to profit" can gather nothing else from the results of the Rothamsted experiments, they may at least learn with what certainty of result certain manurial substances may be employed for the increased production of some of the most important crops which they cultivate ; and I am sure I may safely leave it to the intelligence and the judgment of those I am addressing, to decide, each for himself, how far his own particular soil, and other circumstances, will justify him in modifying his present practice in the direction I have indicated.

Rothamsted, December, 1870.

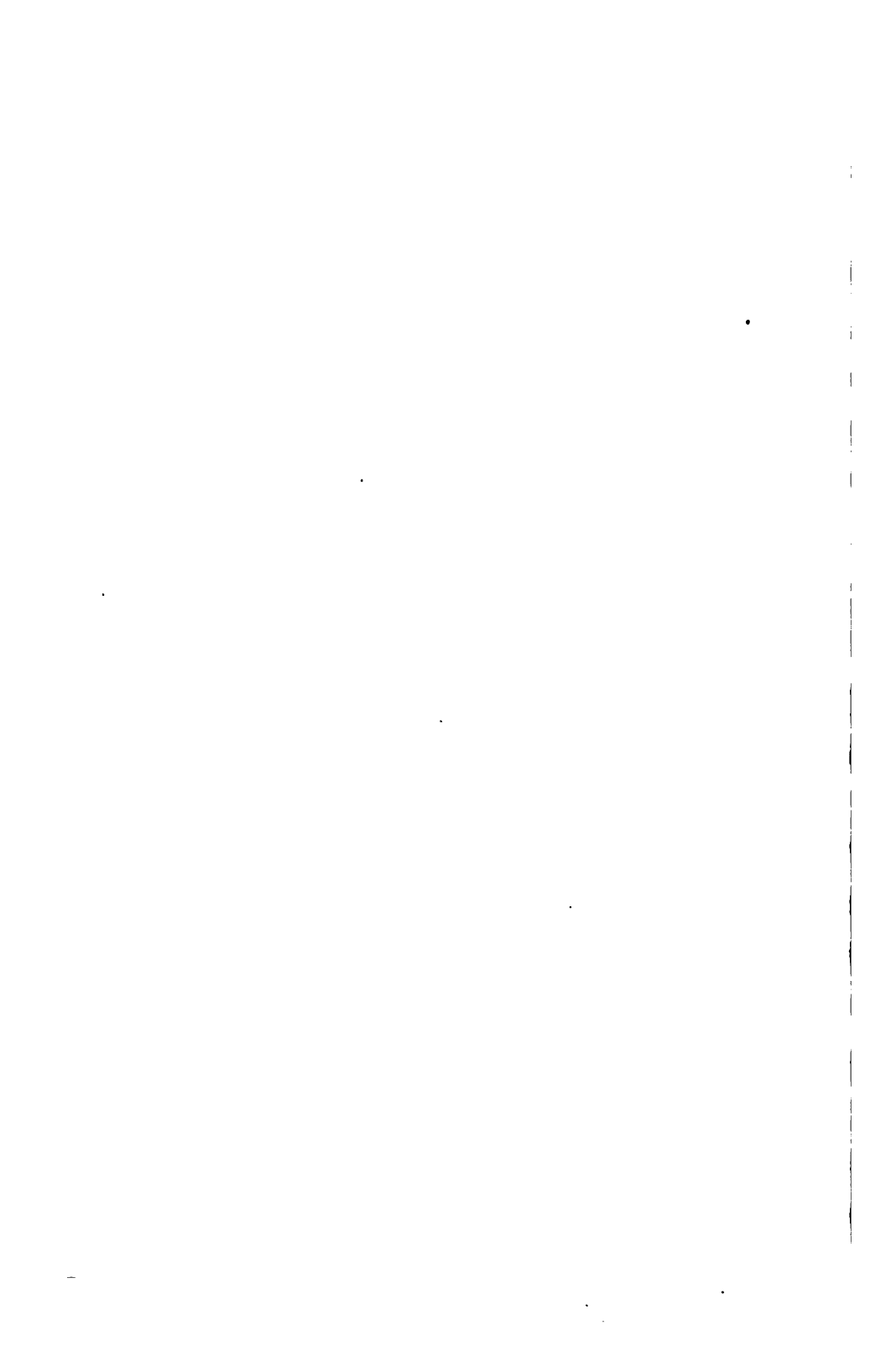


PRINTED AT THE SOUTH EASTERN GAZETTE OFFICE, MAIDSTONE.

1870.

RE-PRINTED BY DUNN & CHIDGEY, 155-7, KINGSLAND ROAD, LONDON, N.E.

1889.



EFFECTS OF THE
DROUGHT OF 1870
ON SOME OF
THE EXPERIMENTAL CROPS
AT ROTHAMSTED.

BY

J. B. LAWES, Esq., F.R.S., F.C.S.,

AND

J. H. GILBERT, Ph.D., F.R.S., F.C.S.

LONDON:

PRINTED BY WILLIAM CLOWES AND SONS, STAMFORD STREET,
AND CHARING CROSS.

1871.

CONTENTS.

	PAGE
INTRODUCTION	3
AMOUNT OF WATER GIVEN OFF BY PLANTS DURING GROWTH	4
RESULTS RELATING TO THE GROWTH OF THE HAY CROP	6
RESULTS RELATING TO THE GROWTH OF WHEAT	17
RESULTS RELATING TO THE GROWTH OF BARLEY	29
SUMMARY, AND GENERAL OBSERVATIONS	35

THE
DROUGHT OF 1870,
AND THE
EXPERIMENTAL CROPS AT ROTHAMSTED.

THE rainfall of Great Britain is usually sufficient for the growth of a considerable variety of crops, in fairly abundant quantity. Indeed, so far at least as the growth of corn is concerned, our fears are of injury from an excess rather than from a deficiency of rain. It is only occasionally, and generally at long intervals, that a season of great drought occurs; and then it is that we forcibly realise how essential for luxuriant vegetation is an abundant supply of water.

Throughout the Midland, Southern, and Eastern portions of England, the year 1870, just past, has been characterised by a season of drought, commencing with the period when vegetation usually becomes active, and extending, with little intermission, to the time when its activity has upon the whole greatly diminished, and in the case of some crops entirely ceased. To find a parallel we must go back to 1844, or more than a quarter of a century. The summer of 1868 was, it is true, one of great drought; and, being hotter than that of 1870, it is not improbable that there was at some periods of it a greater deficiency of moisture in the soil than in the latter year. In fact, those who travelled through the Southern and Midland counties of England in July, 1868, will not soon forget the almost entire absence of green in the meadows, and the intense heat of the atmosphere, resembling more what we read of in tropical countries than the usual experience of our own summers. Although both the drought and heat were more extreme during the months of May, June, and July in 1868 than in 1870, the deficiency of rain commenced a month earlier and extended later last year; and hence, not only the first crops of grass and hay, but also the second growth, suffered much more in the season just past than in 1868.

It is only when crops are grown under precisely similar circumstances, as to manure and other conditions, for many years in succession, that we can obtain satisfactory data for studying the influence of variation of season on the amount and character of the produce. At Rothamsted, as is known to most of the readers of this Journal, numerous experiments on the growth of various crops, each grown year after year on the same land, with different descriptions of manure, the same description

being applied year after year to the same plot, have been carried on without change for many years; in some cases reaching back as far as the drought of 1844, above referred to. Taking advantage of the results so obtained, it is proposed, in the present paper, to consider briefly:—

1. The probable amount of water exhaled during growth by some of our most important crops.
2. The source whence the required supply of water is obtained.
3. The difference of the effects of the drought of 1870 on the different experimental crops.

AMOUNT OF WATER GIVEN OFF BY PLANTS DURING GROWTH.

A series of experiments was commenced in 1849, and was continued for ten years, to determine the amount of water given off by plants during their growth, in relation to the amount of the various constituents they assimilated. Of agricultural plants, wheat, barley, and mixed grasses, as representatives of the Gramineaceous family; beans, peas, and clover, of the Leguminous family; and swedes, white turnips, mangolds, potatoes, and artichokes, as root-crops, were thus experimented upon. Similar experiments were also made on the exhalation by evergreen and deciduous trees, six of each being selected.

The plan of experimenting was as follows:—Cylindrical vessels, first of glass and afterwards of zinc, 14 inches in depth, 9 inches in diameter, and holding about 40 lbs. of soil, were employed. Soil from the plot in the experimental wheat-field which had grown 10 successive crops without manure was selected. The general rule was to make three experiments with each description of plant; one with the above soil without further addition; one with the same soil with purely mineral manure added; and the third with the same soil and both mineral manure and ammonia-salts in addition. In the cases of wheat and barley, plants from three seeds, and of beans, peas, and clover, one plant only, were planted in each vessel. A glass plate, having a hole in the centre about three-quarters of an inch in diameter for the plants to grow through, and another smaller one, closed at pleasure by a cork, for the supply of water, were then firmly cemented upon the top of each vessel. One vessel, supplied with soil and fitted with a glass cover like the rest, was, however, always left without a plant, in order to ascertain the probable amount of evaporation from the surface of the soil itself, through the centre orifice, independently of growth; though, in the experiments with plants, the hole was always partially closed, by laying small pieces of glass over it as far as the stems would allow. Of course in experimenting with root-crops the holes in the glass covers were larger, but they were kept closed around the plants as far as possible, in the manner just described.

The vessel with its contents, weighing more than 40 lbs., was weighed from time to time, generally every ten days during active growth, by means of a delicate balance made for the purpose; which, though carrying so heavy a weight, was capable of indicating a change of a few grains. The plants were of course supplied with water as it was needed. The earlier results, both with agricultural plants and trees, are published in the 'Journal of the Horticultural Society of London,' and to the reports there given we must refer the reader for the details of the inquiry as far as they are yet recorded.*

Referring here only to the results obtained with some of the agricultural plants, it will be sufficient for our present purpose to summarise them as follows:—

1. The amount of water given off by the plants during growth was found to bear relation to the quantity of the total dry matter, or the total non-nitrogenous substance, fixed or assimilated; and within somewhat narrow limits the same relation was observed in the case of both graminaceous and leguminous corn-crops.

2. In relation to a given quantity of water exhaled, twice or three times as much nitrogenous substance is fixed by a leguminous, as by a graminaceous corn-crop.

3. In the growth and ripening of either graminaceous or leguminous corn-crops, probably on the average from 250 to 300 parts of water are given off for 1 part of total dry substance fixed or assimilated.

Before considering the application of this estimate to any special cases, it may be well to give an illustration of its bearing in general terms. Several plots in the experimental wheat-field give an average of about 3 tons of total produce (corn and straw) per acre per annum; and if we assume one-sixth of this to be water, we have remaining $2\frac{1}{2}$ tons of dry substance ripened by the end of July, or the middle of August, each year; and if we further assume that 300 parts of water may be exhaled for 1 part of dry substance fixed, we have $300 \times 2\cdot5 = 750$ tons of water evaporated per acre by the growth of such a crop.

Owing to the difficulty of eliminating surface evaporation other than through the growing herbage, in experiments on the exhalation from a sod of mixed grasses, we cannot so safely adopt a figure to represent the probable average amount of water given off for 1 part of dry substance fixed in their case

* 'Experimental investigation into the amount of water given off by plants during their growth, especially in relation to the fixation and source of their various constituents.'—('Jour. Hort. Soc. Lond.,' vol. v. part i. 1850.)

'Report upon some experiments undertaken at the suggestion of Professor Lindley, to ascertain the comparative evaporating properties of Evergreen and Deciduous Trees.'—('Jour. Hort. Soc. Lond.' vol. vi. parts iii. and iv. 1851.)

as in that of their ripened allies, wheat and barley. We will assume, however, for the purpose of illustration, that in the growth of hay, as in that of the grain-crops, about 300 parts of water will be exhaled for 1 part of dry substance assimilated; and since one of the experimental plots of meadow land at Rothamsted has given an average, over fifteen years, of 3 tons of hay, or about $2\frac{1}{2}$ tons of dry substance per acre per annum, its growth would again represent an exhalation of about 750 tons of water per acre per annum—but extending in this case not later than to the middle or end of June.

We will now adduce some special cases illustrating the amount of water exhaled by different crops, and their dependence on the rainfall of the period of active growth, or on the supplies of moisture previously accumulated within the soil.

RESULTS RELATING TO THE GROWTH OF THE HAY-CROP.

The following Table (I.) shows the amount of hay obtained per acre each year for fifteen years in succession (1856-1870):—

1. Without manure.

2. With mixed mineral manure and 400 lbs. ammonia-salts per acre per annum.

3. With mixed mineral manure and 550 lbs. nitrate of soda per acre per annum (thirteen years only, 1858-1870).

The Table also shows, side by side with the records of produce, the amount of rain, in inches, which fell at Rothamsted each year

TABLE I.

Years.	HAY PER ACRE.				RAIN AT ROTHAMSTED.			
	Without Manure.	Mineral Manure and Ammonia-salts.	Mineral Manure and Nitrate of Soda.	Mean.	April.	May.	June.	Total.
	Cwts.	Cwts.	Cwts.	Cwts.	Inches.	Inches.	Inches.	Inches.
1856	22 $\frac{1}{2}$	56 $\frac{3}{4}$	..	39 $\frac{1}{2}$	2·61	4·70	1·91	9·22
1857	25 $\frac{1}{2}$	57 $\frac{1}{2}$	..	41 $\frac{1}{2}$	2·16	1·10	2·21	5·47
1858	22	64	50 $\frac{1}{2}$	45 $\frac{1}{2}$	2·58	2·55	0·96	6·09
1859	22 $\frac{1}{2}$	55 $\frac{1}{2}$	54 $\frac{1}{2}$	44	2·70	2·09	2·72	7·51
1860	24 $\frac{1}{2}$	50 $\frac{1}{2}$	49 $\frac{1}{2}$	41 $\frac{1}{2}$	1·94	4·30	6·26	12·50
1861	25 $\frac{1}{2}$	56 $\frac{3}{4}$	52 $\frac{1}{2}$	44 $\frac{1}{2}$	1·28	1·04	2·98	5·30
1862	27 $\frac{1}{2}$	57 $\frac{1}{2}$	51	45 $\frac{1}{2}$	2·84	2·91	3·41	9·16
1863	20 $\frac{1}{2}$	53 $\frac{1}{2}$	58 $\frac{1}{2}$	44 $\frac{1}{2}$	0·96	1·01	4·60	6·57
1864	24	50 $\frac{1}{2}$	60 $\frac{1}{2}$	45	1·25	1·88	1·79	4·92
1865	11 $\frac{1}{2}$	34 $\frac{1}{2}$	47 $\frac{1}{2}$	31 $\frac{1}{2}$	0·47	3·05	0·68	4·20
1866	23 $\frac{1}{2}$	44 $\frac{1}{2}$	58 $\frac{1}{2}$	42 $\frac{1}{2}$	1·95	1·24	4·51	7·70
1867	29 $\frac{1}{2}$	48	64 $\frac{1}{2}$	47 $\frac{1}{2}$	2·82	3·35	1·06	7·23
1868	17 $\frac{1}{2}$	59 $\frac{1}{2}$	69	48 $\frac{1}{2}$	2·19	0·73	0·37	3·29
1869	38	68 $\frac{1}{2}$	76 $\frac{1}{2}$	61	2·13	3·23	1·07	6·43
1870	5 $\frac{1}{2}$	29 $\frac{1}{2}$	56 $\frac{1}{2}$	30 $\frac{1}{2}$	0·46	1·35	0·98	2·79
Average	22 $\frac{1}{2}$	52 $\frac{1}{2}$	57 $\frac{1}{2}$	43 $\frac{1}{2}$	1·89	2·30	2·37	6·56

during the months of April, May, and June, which may be considered as including the period of active growth of the hay-crop.

Although there is much to be learnt from the results brought together in the foregoing Table, much more information than is there given would be required—as to the difference in the character of the herbage produced under the different conditions, the distribution of the rain, the degree and range of temperature, and the mutual adaptations of moisture, heat, and stage of growth of the plants—to enable us to account for all the fluctuations in the amounts of gross produce which the records show.

It is seen at a glance that the fluctuations from year to year in the amounts of produce without manure, though doubtless greatly dependent on the quantity and distribution of the rain falling during the period of active growth, by no means correspond with the fluctuations in the total amount of rain during the three months. Thus, the average fall for the three months is 6·56 inches, and the average produce of hay without manure is 22½ cwt. But we have, with almost exactly the same total amount of rain during the same period in 1863 (6·57 inches), only 20¾ cwt. of hay; whereas, with even rather less (6·43 inches), in 1869, we have the heaviest produce obtained in any one of the series of 15 years, namely, 38 cwt. The fact is that, coincidentally with the small produce of 1863, less than one-third of the total rainfall of the three months occurred during the first two months of the period; whilst, coincidentally with the very heavy produce in 1869, there was considerably more than the average fall of rain in both April and May, and less than half the average fall in June; the result being that more than five-sixths of the total fell during the first two of the three months, when its influence upon the growth would be the greatest. Again, the heaviest total fall within the growing period was in 1860, when there was nearly double the average amount, whilst the produce only exceeded the average by less than 2 cwt. of hay; the facts being, that about half the total amount fell in June, that is, not until the last month of growth; and that the temperature was very unusually low almost throughout the period of active vegetation.

The lowest amounts of produce were—17½ cwt. in 1868, 11½ cwt. in 1865, and only 5½ cwt. in 1870. This last, the lowest amount in the series, is coincident with the smallest amount of total rain over the three months throughout the fifteen years, namely 2·79 inches. With only 3·29 inches in the three months of 1868, there was a produce of 17½ cwt., but with 4·2 inches in 1865, there was only 11½ cwt. But whilst, in the latter year, there was in April only about one-fourth the average fall, and very high

temperature, there was during the same month in 1868 more than the average fall, and about the average temperature.

Turning to the columns of produce obtained by the two artificial manures, it is seen that, whilst in the earlier years the mineral manure and ammonia-salts gave more hay than the mineral manure and nitrate of soda, in the later years the mineral manure and nitrate yielded considerably more than the mineral manure and ammonia-salts. It is obvious, therefore, that the fluctuations in the produce are dependent on other conditions than the variations in external or climatic circumstances alone. It will come within the special province of our subject to explain this further presently; but, in passing, we may here remark that the character of the mixed herbage in regard to the distribution of plants, and the prevalence of individual species, was very widely different in the two cases; and the dependence of the amount of produce on external supplies of moisture will, of course, be greatly measured by the degree of root range, and the consequent command of the moisture within the soil itself, of the particular species favoured.

These few observations will be sufficient to indicate some of the points of interest which the study of the subject in detail is calculated to elucidate, and to show the complexity of the conditions upon which the final result—the weight of hay—depends.

We will now turn to the more special object of the present communication.

The following are the amounts of hay obtained per acre in 1870, on each of the three plots already referred to, and also the average amounts over 15 years without manure, and with mineral manure and ammonia-salts, and over 13 years with mineral manure and nitrate of soda.

TABLE II.

	HAY PER ACRE.		
	1870.	Average 15 (or 13) Years, 1856-70.	Deficiency in 1870.
	Cwts.	Cwts.	Cwts.
Without manure	5½	22½	17
Mineral manure and ammonia-salts ..	29½	52½	23½
Mineral manure and nitrate of soda ..	56½	57½	1½

Thus, under the influence of the extraordinary drought of 1870, there was a variation in the amount of produce on closely adjoining plots, from only 5½ cwts. of hay without manure, to

29½ cwts. with mineral manure and ammonia-salts, and to 56½ cwts. with mineral manure and nitrate of soda. Indeed, without manure there was not only less produce than in any preceding year of the fifteen, but only about one-fourth the average amount. With mineral manure and ammonia-salts there was again considerably lower produce than in any other of the fifteen years with the same manure, and a deficiency of nearly 23 cwts. compared with the average. Notwithstanding this, we have the remarkable result of 2 tons 16 cwts. of hay produced by mineral manure and nitrate of soda, or only about 1¼ cwt. less than the average amount by that manure; about 2½ tons more than without manure, and 1½ ton more than by the mixture of mineral manure and an amount of ammonia-salts containing about the same quantity of nitrogen as the nitrate.

On the assumption that probably about 300 parts of water pass through the plants for one part of dry substance fixed, about 700 tons of water must have been exhaled by the herbage during the growth of the 56 cwts. of hay. But, reckoning an inch of rain to represent a fall of 101 tons per acre, the 2.79 inches which fell in 1870 during April, May, and June, the period of active vegetation, could only supply 282 tons of this, provided (which would not be the case) none of it was lost by drainage, and none of it passed off by evaporation otherwise than through the plants themselves. On the same assumptions, the amount which fell would be about 160 tons less than sufficient for the requirements of the crop grown by mineral manure and ammonia-salts, but more than three times as much as would be required by the growth of the unmanured produce.

So striking was the difference in the effect of the drought on two plots side by side, the one manured with mineral manure and a given quantity of nitrogen in the form of ammonia-salts, and the other with the same mineral manure and the same quantity of nitrogen, but the latter in the form of nitrate of soda instead of ammonia-salts, that it was decided, on the removal of the crop, to determine the quantities of water existing in the soil of the three plots to a depth somewhat greater than the lowest to which roots could be traced; and also to observe the difference in the development and distribution of the roots, if any, on the different plots. Accordingly, on July 25 and 26, 1870, samples of soil were taken from the three plots to the depth of 54 inches in each case, roots having been traced on one of them to within a few inches of that depth.

The plan of collecting and preparing samples of soil for analysis will be understood from the following description of the process in the present instance: A square yard, comprising a fair proportion of the species contributing to the bulk of the herbage,

having been carefully selected on each plot, a case or frame, open at the top and bottom, made of strong sheet-iron, 6 inches square by 9 inches deep (but which may be of any desired size), was driven into the ground in the centre of the square, level with the surface. The enclosed soil was then dug out exactly to the depth of the case. The soil around the case, to the extent of the square yard selected, was then removed to the level of the bottom of it; it was again driven down, and its contents carefully taken out; and so on, the process was repeated, until the desired depth was attained. The determination of the water in the samples being the special object of the experiments in question, the exact weight of the soil was taken immediately on removal, so that any loss of moisture by evaporation during preservation, or preparation for analysis, might be duly taken account of. The whole was then broken up, the stones sifted out, separating first those which did not pass a 1-inch sieve, next a $\frac{1}{2}$ -inch, and finally a $\frac{1}{4}$ -inch sieve being used. The mould, or soil, passing the $\frac{1}{4}$ -inch sieve was weighed, a proportional part of it finely powdered for analysis and re-weighed. In the soils so prepared, the loss of moisture, at different temperatures, has been, and the nitrogen and some other constituents will be determined.

The following Table shows the percentage of moisture, as determined by the loss when dried at 212° Fahr., inclusive of that by evaporation during preparation for analysis, in the soil from each of the three plots of the experimental meadow-land, at each depth to which the samples were taken :—

TABLE III.—MOISTURE in the Soil from Plots of Permanent Meadow Land differently Manured. Samples collected July 25–6, 1870.

Depth of Sample.	PERCENTAGES OF MOISTURE (Soils dried at 212° Fahr.).		
	Plot 3. Without Manure.	Plot 9. Mineral Manure and Ammonia-salts.	Plot 14. Mineral Manure and Nitrate of Soda.
First 9 inches	10·83	13·00	12·16
Second 9 inches	13·34	10·18	11·80
Third 9 inches	19·23	16·46	15·65
Fourth 9 inches	22·71	18·96	16·30
Fifth 9 inches	24·28	20·54	17·18
Sixth 9 inches	25·07	21·34	18·06
Mean	19·24	16·75	15·19

The results recorded in this Table are of great interest and significance; and they supply important data towards the explanation of the extraordinary difference in the amount of produce obtained on the different plots. It should be premised, however,

that between the removal of the crops and the date of sampling the soils, in all nearly an inch of rain had fallen, perhaps affecting somewhat the actual percentages, but the relative amounts probably but little.

The first point to remark is, that the first 9 inches of soil of both the heavily manured, and more or less heavily cropped, plots contained a higher percentage of moisture than that of the unmanured and lightly cropped plot. But from that point downwards to a depth of 54 inches, and doubtless further still, the manured and more heavily cropped soils contained much less moisture than the unmanured; and the most heavily cropped soil, that of Plot 14, manured with mineral manure and nitrate of soda, contained considerably less than that of Plot 9, manured with mineral manure and ammonia-salts. And whilst at a depth of from 45 to 54 inches the unmanured soil contained 25 per cent. of moisture, that receiving mineral manure and ammonia-salts contained only 21·34 per cent.; and that receiving mineral manure and nitrate of soda only 18 per cent., or scarcely $\frac{2}{3}$ ths as much as the unmanured soil at the same depth. To sum up the results, there is an average amount of moisture down to the depth of 54 inches, of 19 $\frac{1}{4}$ per cent. on the plot without manure, of only 16 $\frac{1}{2}$ per cent. on the plot manured with mineral manure and ammonia-salts, and of scarcely 15 $\frac{1}{4}$ per cent. on that manured with mineral manure and nitrate of soda, or only about $\frac{1}{3}$ ths as much on the latter as on the unmanured plot.

The subsoil of this meadow land is a reddish yellow clay, interspersed with grey veins, and the specific gravity increases by about one-half from the surface down to the greatest depth taken. For our present purpose it will be a sufficiently near approximation to the truth to assume that down to the depth of 54 inches, the soil (exclusive of stones) weighed an *average* of 1,000,000 lbs. per acre for every 3 inches of depth, or an aggregate of 18,000,000 lbs. per acre to the depth of 54 inches. Adopting this estimate, and the percentages of moisture given in Table III., it results that down to the depth of 54 inches, or 4 feet 6 inches, the unmanured soil retained 1546, the soil of Plot 9, 1346, and that of Plot 14, 1221 tons of water. That is to say, to the depth of 4 feet 6 inches, the soil of Plot 9, manured with mineral manure and ammonia-salts, contained 200 tons, and that of Plot 14, manured with mineral manure and nitrate of soda, 325 tons less water per acre than that of the unmanured soil to the same depth; whilst, from the great difference in the percentage at the lowest depths taken in the three cases, there can be no doubt that the difference extended considerably deeper still.

Here, then, we have evidence of the source whence the ma-

nured crops derived the water required for their growth, over and above that supplied by the rain actually falling during the period of active vegetation. But the questions obviously arise—if the unmanured subsoil retained so much more water, why did the crop suffer from the drought so very much more than the manured crops? and why did the crop manured with mineral manure and ammonia-salts suffer so much more than that manured with mineral manure and nitrate of soda, and not avail itself so fully as did the latter of the stores of moisture within the soil? To gain some information on the points here suggested, careful examination was made of the distribution of species on the square yard of the plot selected, of the section of the soil and subsoil, and of the distribution of roots within them.

It should be stated that 53 species in all are found on the continuously unmanured plot; this great complexity of herbage being maintained in consequence of the little encouragement to luxuriance of any. On the other hand, by the application of mineral manure and ammonia-salts on Plot 9, and of mineral manure and nitrate of soda on Plot 14, for many years in succession, and the consequent great encouragement and predominance of certain individual species, the total number discernible has become reduced to 30 on each of these plots. And whilst the herbage on the unmanured plot comprises 17 graminaceous, 4 leguminous, and 32 miscellaneous or weedy species, that of Plot 9 includes only 15 graminaceous, 2 leguminous, and 13 miscellaneous species, and that of Plot 14 only 14 graminaceous, 3 leguminous, and 13 miscellaneous species.

But such, again, is the difference in the character of the two nitrogenous manures—ammonia-salts and nitrate of soda—in regard to their reactions upon the soil, and the consequent degree of rapidity and range of distribution of them or their products of decomposition within it, that they respectively encourage the development of species of widely different underground, as well as above-ground habit of growth. Thus, the dominant plants were very different on the two manured plots. Under the influence of the annual application of mineral manure and ammonia-salts, *Dactylis glomerata* (rough cock's-foot), *Agrostis vulgaris* (common bent-grass), *Festuca ovina* (sheep's-fescue), and *Poa pratensis* (common meadow-grass), among graminaceous plants, and *Rumex acetosa* (sorrel-dock), among the miscellaneous herbage, prevailed somewhat in the order of enumeration; whilst under the influence of mineral manure and nitrate of soda *Bromus mollis* (soft brome-grass), had become so prominent as to constitute probably about one-half the crop; *Poa trivialis* (rough meadow-grass) was also very prominent, *Holcus lanatus* (woolly soft-grass),

Festuca ovina (sheep's-fescue), *Lolium perenne* (rye-grass), *Dactylis glomerata* (rough cock's-foot), *Avena flavescens* (yellow oat-grass), and among weeds *Anthriscus sylvestris* (wild beaked-parsley), coming next in order of prevalence. And, whilst the plants most encouraged by the ammonia-salts have a tufty habit of growth above ground, and a tendency to luxuriate within a limited range beneath the surface, some of those most favoured by the nitrate of soda, and especially under its influence, are very different in character, not growing in tufts, but producing comparatively uniformly dense herbage, with many stems, comparatively few root-leaves, and roots having a characteristically downward tendency, those of the *Bromus mollis* especially (which contributed such a large proportion of the whole crop) being strong and wiry, and descending far into the subsoil.

The sectional examinations, indeed, showed great differences in the character of the turf, in the prevalence and character of development of the roots within and below it, and in the character of the soil and subsoil, as the following brief abstract of the observations made will show. It should be first stated, however, that whilst on the square yard selected as characteristic of the unmanured plot, there were found 9 graminaceous, 4 leguminous, and 11 miscellaneous—in all 24 species; on that of Plot 9, having mineral manure and ammonia-salts, there were only 6 graminaceous, no leguminous, and only 3 miscellaneous species; and on that of Plot 14, receiving mineral manure and nitrate of soda, again only 6 graminaceous, only 1 leguminous, and 2 miscellaneous species.

Owing to the great complexity of the herbage on the unmanured plot, including a comparatively large number of leguminous, and miscellaneous or weedy species, some fleshy roots were observed at a considerable depth. The turf consisted of a complex network of fine roots and fibrils, which were much less in size and strength than in the case of either of the manured plots. These fine roots seemed to have more or less complete possession of the soil to a depth of about 6 inches, and some of them then showed a downward tendency; becoming, however, much fewer, and even in the second and third 9 inches extremely fine; and at a depth of about 40 inches they were as fine as a fibre of silk or a spider's web. It was concluded, though not with great certainty, that the roots found at the greatest depth were those of *Agrostis vulgaris* and *Bromus mollis*. The sample of the first 9 inches of the unmanured soil possessed the character of mould not much less than that of the manured plots; the second 9 inches, too, was very much altered from the character of the clay subsoil; but below this point very slight difference was observ-

able; though, of the four lower samples, the uppermost, that is, the third from the surface, perhaps showed slightly the least, and the lowest, or sixth, the brightest red tinge.

The turf of Plot 9, manured with mineral manure and ammonia-salts, consisted of a dense, almost peat-like mass, of decomposing roots, radicle leaves, and stubble, thickly penetrated with strong roots and fibrils, the whole being as much matted as on the unmanured soil, showing, however, less complexity, but greater strength of roots. The horizontal subterranean stems of the *Agrostis vulgaris* greatly predominated, emitting many fibrils, and sending out many descending fibrous roots. *Poa pratensis* also developed a large amount of strong root, and a profusion of fibrils. Roots penetrated to about the same depth as on Plot 3, but in larger quantity, and of larger size; being, however, in the fifth 9 inches, both very few in number and very fine. As already said, the samples of the first 9 inches of the soil of the three plots differed comparatively little from one another in the degree of their change by the action of vegetation; but, if anything, that of this Plot 9 was the darkest, indicating so far more of mould-like character. The second 9 inches of this plot was decidedly more changed than that of the unmanured, or of even Plot 14. The third and fourth 9 inches were, compared with the unmanured, slightly darker, or less bright in colour, showing still some change. The fifth and sixth were little, if at all, distinguishable in colour from the raw, reddish-yellow clay of the unmanured plot at corresponding depths.

The turf of Plot 14, manured with mineral manure and nitrate of soda, had not the peaty appearance of that of Plot 9; the prevailing plant, *Bromus mollis*, which made up about half the crop, possessing comparatively few radicle leaves; whilst, especially under the influence of this manure, *Poa trivialis*, *Holcus lanatus*, and *Lolium perenne*, have a tendency to assume the same character of development above ground. The *Bromus mollis*, too, was found in a most striking degree to send down strong wiry roots into the subsoil, leaving only its fibrils, and the roots of less prominent or smaller species, to feed near the surface. The second 3 inches of soil also held together, being full of fibre. At the extremity of the fibrils of the *Bromus mollis* small tubercles, much like those which occur on the roots of some leguminous plants, were observed down to a depth of perhaps 12 or 14 inches. The roots of this grass extended, however, to a depth of nearly 4 feet, still maintaining their wiry character. The difference in the character of the samples of soil, and especially of the subsoil, of this compared with those of either of the other plots, was very striking. The first 9 inches differed little from that of the unmanured plot. The second was, however, more altered

than that of the unmanured plot at the corresponding depth. The third, fourth, fifth, and sixth 9 inches were very strikingly different in appearance from the corresponding layers of either of the other two plots; the clay, instead of being of a comparatively uniform reddish yellow colour, was very much mottled or veined, showing a mixture of yellow, grey, red, and brown, with the yellow and grey predominating. So much was this the case that when the samples were powdered they were of a yellowish grey colour, instead of reddish yellow; and the lighter or less yellow the greater the depth of the sample, that of the sixth 9 inches being the lightest of all.

There was, perhaps, more of natural grey vein in the subsoil of this than in that of the other plots, but the difference in colour and texture was too great to be so accounted for. Upon the whole the lower layers were softer and more soapy than in the case of either Plot 3 or Plot 9; though, as Table III. at page 10 shows, they contained a considerably less percentage of moisture. Indeed, the subsoil of this plot had much more the appearance of disintegration from some cause than that of either of the others; it was consequently much more easily worked, and especially more so than that of the unmanured plot, which was very tough and hard.

To sum up these distinctions: it is seen that not only did different plants become dominant according to the different condition of the plot as to manure, but those which prevailed on the unmanured land, though numerous, had much finer and much less vigorous roots; the raw clay of the subsoil was much less changed; and it had yielded up very much less moisture to the growing crop. On the plot manured with mineral manure and ammonia-salts free-growing grasses predominated; but chiefly those whose underground habit of growth was such as rendered them dependent for their food and moisture in great measure on that which is to be found in the upper layers of the soil. Still, owing to the increased vigour of growth under the influence of the manure, it is seen that moisture was obtained, either directly by the roots of the plants, or by capillary action induced by the pumping out of the upper layers, from the extreme depths to which the samples were taken; and, from the great difference in the percentage of moisture at that depth compared with that of the unmanured plot, there is no doubt that the action extended deeper still. On Plot 14, on the other hand, where nitrate of soda was applied, the plant which contributed about half the produce had roots of a very characteristically downward tendency. We find the soil, to the depths examined, pumped drier still; and, coincidentally, the drought has comparatively little affected the amount of the crop.

Intimately connected with the greater change in the subsoil of the plot manured with nitrate of soda than in that manured with ammonia-salts, with the greater predominance and luxuriance of the deeper-feeding herbage, and with the consequent little evil effects from the drought where the nitrate was employed, is doubtless the fact that the ammonia of the ammonia-salts is much more readily absorbed and retained by the soil than is the nitric acid of the nitrate. The latter, consequently, becomes, under the influence of rain, more rapidly distributed and washed into the subsoil, whither the roots follow it. As this filtration, into and through the subsoil, of a solution of the nitrate, or of its products of decomposition within the soil, has been proceeding for thirteen years in succession, there is little cause for surprise that the subsoil should have become much more changed than where the ammonia-salts had been used. It seems intelligible, too, that those plants of the herbage, whose habit of growth is characterised by a comparatively large development of descending roots, aided as they would be when once they had asserted their predominance by more and more self-sowing each succeeding year, should get such complete possession of the lower layers of the soil, with their stores of food and moisture. On this point it may be remarked, that the *Bromus mollis*, which so strikingly predominated on the nitrated plot, and whose roots, though only a biennial, had obtained more complete possession of the subsoil than those of any other plant, is one of the earliest of the grasses, and has, in point of fact, generally seeded to a greater or less extent before the crop has been cut.

It may be here mentioned in passing, that, wherever, in the course of the experiments at Rothamsted, nitrate of soda is employed year after year on the same plot of arable land, the difference in the appearance and texture of the soil is very great, and is discernible at a considerable distance. The soil apparently retains very much more moisture, becomes more agglutinated, and so sticky compared with that of adjoining plots under equal conditions of weather, as to be with difficulty worked at the same time, and never brought to the same tilth without the expenditure of extra labour upon it. It may be judged, indeed, that during the wet season the nitrated soil, and its more disintegrated subsoil, would acquire more moisture, or at least more available moisture, than the soil and raw clayey subsoil of the other plots.

We have, then, in the properties of the nitrate of soda and its effects upon the soil and subsoil, in the influence of these in determining the character of the prevailing herbage, and in the comparative independence of external sources of moisture which a deep root range gives to the plants encouraged, an explanation

of the fact that, notwithstanding the unusual drought of 1870, which almost suspended the growth of the unmanured herbage, and much diminished that manured with mineral manure and ammonia-salts, the plants which had gradually asserted possession over others on the plot continuously manured with mineral manure and nitrate of soda, should have yielded, under the same circumstances of scarcity of rain, an all but average crop.

Before leaving the subject of the influence of the drought of 1870 on the hay-crop, it may be added that a portion of the park adjoining the experimental plots was liberally manured with London stable-dung, but no benefit whatever was apparent, and the crop was so light as to be scarcely worth mowing.

The evidence at command in regard to the effects of the drought on other of the experimental crops, is not of the same, or in some respects of so direct a kind, as that relating to the mixed herbage, and to the soils, of the experimental plots of grass land. Nevertheless, some facts of interest may be recorded illustrating the influence of the moisture stored up within the soil on the growth of both wheat and barley.

RESULTS RELATING TO THE GROWTH OF WHEAT.

The following Table (IV.) shows the amounts of grain, and the amounts of total produce (corn and straw together), obtained in the experimental wheat-field for 19 years in succession, 1852-1870 inclusive:—

1. On Plot 3, continuously unmanured.
2. On Plot 2, receiving 14 tons farmyard manure per acre per annum.
3. On Plot 7, receiving, annually, mixed mineral manure, and 400 lbs. ammonia-salts per acre.
4. On Plot 9A, receiving, annually, the same mixed mineral manure as plot 7, and 550 lbs. nitrate of soda per acre.

The Table also shows, side by side with the amounts of produce, the fall of rain each year during the months of April, May, June, and July, which may be said to include the period of active vegetation and accumulation of substance. It should be further explained, that, in order that the different amounts of grain from year to year may be more strictly comparable one with another, and to avoid the necessity of recording and considering the weight per bushel in each case, the total weight of dressed corn has been divided by 61, and the Table shows, therefore, not the actual number of measured bushels in each case, but the number of bushels of an assumed uniform weight of 61 lbs.

TABLE IV.—Produce of Wheat by different Manures, and fall of Rain during the 4 Months of active growth each Year, for 19 Years, 1852—1870.

YEARS.	DRESSED CORN. (In Bushels of 61 lbs.)					TOTAL PRODUCE. (Corn and Straw.)					RAIN AT ROTHEMPTED.				
	PLOT 3.	PLOT 2.	PLOT 1st.	PLOT 9a.	MEAN.	PLOT 3.	PLOT 2.	PLOT 1st.	PLOT 9a.	MEAN.	APRIL.	MAY.	JUNE.	JULY.	TOTAL.
	Without Manure.	Farmyard Manure.	Mineral Manure and Ammonia-salts.	Mineral Manure and Nitrate Soda.		Without Manure.	Farmyard Manure.	Mineral Manure and Ammonia-salts.	Mineral Manure and Nitrate Soda.		Inches.	Inches.	Inches.	Inches.	Inches.
1852	12½	26½	24½	(1)	21½	24½	5173	5440	1	4357	0.52	1.84	4.70	2.28	9.34
1853	4½	16	20½	(1)	13½	1772	4492	5101	(1)	3788	3.00	1.73	3.47	4.49	12.69
1854	20½	42½	46½	(1)	36½	2859	7115	8497	(1)	6373	0.49	4.58	0.77	0.86	6.50
1855	16½	35½	39½	28½	26½	3486	6082	6146	5878	5241	0.41	2.32	1.65	6.97	11.35
1856	12½	34½	37½	30½	28½	2450	6594	6757	5894	5424	2.61	4.70	1.91	1.48	10.70
1857	19	40½	44½	43½	36½	2813	5910	6628	6634	5486	2.16	1.10	2.21	1.61	7.08
1858	17½	39½	39½	37½	33½	2811	6349	6519	6701	5595	2.58	2.55	0.96	3.19	9.28
1859	15½	33½	31½	26½	27	3226	7073	6833	7076	6052	2.70	2.09	2.72	3.02	10.53
1860	11½	29½	24½	27½	23½	2197	5304	4675	6635	4703	1.94	4.30	6.26	1.99	14.49
1861	10½	34½	33½	31½	27½	1990	5303	5751	6607	4913	1.28	1.04	2.98	3.19	8.49
1862	15½	36½	34½	42½	32½	2709	6642	6143	8738	6088	2.84	2.91	3.41	1.80	10.96
1863	17½	45½	55	56½	43½	2727	7165	9358	9888	7284	0.96	1.01	4.60	0.70	7.37
1864	16½	41	47½	52½	39½	2428	6488	7970	9315	6531	1.25	1.88	1.79	0.89	5.81
1865	13½	37½	40½	44½	33½	1861	5484	6249	7563	5289	0.47	3.05	0.68	2.93	7.13
1866	12½	33	29½	32½	26½	2046	6128	5775	7377	5314	1.95	1.24	4.51	3.01	10.71
1867	8½	27½	29½	28½	21½	1505	4891	4179	6773	4337	2.82	3.35	1.06	4.10	11.33
1868	10½	42½	36½	47½	36½	2027	6794	6317	8150	5822	2.19	0.73	0.37	0.37	3.66
1869	13½	35½	26½	36½	28	2198	6193	4972	7298	5165	2.13	3.23	1.07	0.97	7.40
1870	15½	38	42	46½	35½	2002	5092	5836	6851	4946	0.46	1.35	0.98	1.12	3.91
Averages	14½	35½	35½	38½ (1)	30½	2398	6016	6267	7336 (1)	5406	1.72	2.36	2.43	2.37	8.88

(1) In 1852, 1853, and 1854, there was no mineral manure employed on plot 9a, and the amounts of nitrate used were less than the quantity mentioned in the text. Hence the produce is not given for these years; and the average produce by the mineral manure and nitrate is taken over 16 years only.

The evidence afforded by the results in the foregoing Table is confessedly quite inadequate to show what are the climatic conditions favourable or otherwise to the growth of wheat. It is, however, quite sufficient for our present purpose, which is to illustrate the comparative independence of the crop on the mere amount of rain falling during the period of active vegetation. It will suffice to call attention to a few of the more extreme examples.

The four years of largest total fall of rain over the four months in question were, 1853, 1855, 1860, and 1867, and three of them were also the seasons of smallest average crop, both of corn and total produce, whilst the fourth (1855) was a season of generally less than the average produce. On the other hand, the three years of highest produce, both corn and total produce, were 1854, 1863, and 1864, and all three were seasons of less than the average fall of rain during the four months of active growth. Lastly, the two seasons of lowest fall of rain during April, May, June, and July were 1868 and 1870; and both gave, with each of the four conditions as to manure, more than the average produce of corn over the nineteen years; and in 1868, though not in 1870, there was even more than the average of total produce also, under each of the three manured conditions. But although there was, in both these years of great deficiency of rain during the growing period, more than the average produce of corn without manure, there was, in both, less than the average amount of both straw and total produce.

As in the case of the hay crop, so again with the wheat, it is seen that, whilst during the earlier years the mineral manure and ammonia-salts gave more produce, both corn and total produce, than the mineral manure and nitrate of soda, during the later years the nitrate has given more, and sometimes considerably more, of straw especially, than the mineral manure and ammonia-salts. The questions arise, how far may this be due: to the more rapid and more extended distribution of the nitrate of soda, or its products of decomposition, within the soil and subsoil? to the mutual reactions of the manure and the soil? to the greater power of retention of moisture acquired by the latter, as the result of such reaction? and to more active root development in the spring under these conditions?

Unfortunately, no comparative determinations of moisture in the soils of these two plots, or of root development, have been made, so as to obtain direct evidence in regard to the questions here suggested. Due weight should, however, be given to the fact that, whilst the ammonia-salts are sown in the autumn, before the seed, the nitrate is applied as a top-dressing in March. It is known that nitrate of soda, or its nitric acid in combination with some other

base, distributes more rapidly, and, under equal circumstances as to rain, is more liable to be washed into the subsoil or the drains, than is the ammonia of the ammonia-salts. Hence it is not applied until the commencement of active growth, when the plant is able rapidly to avail itself of it. It is also known that a portion of the ammonia of the ammonia-salts itself becomes converted into nitric acid, and then is subject, in like manner, to loss by drainage; but to what degree a saturated condition of the soil during winter may cause serious loss, in this way, of the ammonia applied as ammonia-salts in the autumn, is a question not yet sufficiently investigated, and to which we shall make some further reference before concluding.

Although, as has been said, there is no evidence at command in regard to wheat, in reference to the questions above raised, so direct as that referring to the meadow land, yet the results now to be adduced nevertheless supply interesting and important data in respect to the variation in the amount of moisture within the soil at different depths, as affected by season, by manure, and by the growth of the crop.

Such were the drought and heat of May, June, and July, 1868, that it is hardly possible to suppose conditions more calculated to induce extreme dryness of soil than those preceding the harvest of that year. Accordingly, towards the end of July, just before the crop was ripe, samples of soil were taken from three plots of the experimental wheat-field, with the special view of determining the amount of moisture retained at different depths. The plots selected were:—

Plot 3. Without manure, since 1839.

Plot 2. With 14 tons farmyard manure per acre per annum.

Plot 8a. With mixed mineral manure, and 600 lbs. ammonia-salts per acre per annum.

The mode of collecting the samples was that already described, excepting that the iron frames employed were only 3 inches deep, instead of 9; the object being to determine the amounts of moisture at each 3 inches of depth, down to a total depth of 36 inches, or rather below the pipe-drains.

The subsoil of the farm consists of a tolerably tenacious reddish-yellow clay, resting upon chalk, and the corn crops seldom suffer from a scarcity of rain. At the time the samples were taken, the wheat had suffered but little from the drought, as the results already quoted show. But barley and oats were exceedingly light crops, and a bean crop in an adjoining field was quite dried up and dead for want of moisture.

For comparison with these samples taken at a time of extreme dryness, others were collected from the same plots in January, 1869, after much rain during the preceding ten days;

the drains were running, and it was supposed that the ground was quite saturated. It was, indeed, so wet that it was necessary to lay down boards for the men to stand upon whilst working.

Table V., overleaf, shows the percentages of moisture in the different samples of soil; bringing together—first, the results for the three plots during the drought; second, those for the three plots when the land was saturated; and lastly, the same results arranged for the convenient comparison of the percentages in the dry state and the wet state, and showing the difference between the two, for each plot separately.

It will be obvious that the amount of water at the different depths in July, 1868, after about three months of great deficiency of rain, and the growth of a crop then approaching ripeness, must, in the main, be dependent on the supplies accumulated during the previous winter and early spring. But it is affected, to a greater or less depth from the surface: by any difference of texture and power of absorption, the result of previous cultivation, manuring, and cropping; by the influence of the pipe-drains, which are at a depth of about 30 inches; also, by the shade of the crop on the one hand, lessening evaporation from the soil itself, and on the other, by the requirements of the growing crop increasing, according to its amount, the exhalation through the plants themselves, and the consequent pumping out of the stores within the soil.

The soil of Plot 3, which had received no manure and produced little root (tending to disintegrate the soil and increase its absorptive surface), which had comparatively little shade from the growing plants, preventing surface evaporation, and whose crop would exhale comparatively little, is seen to retain a somewhat less percentage of water than either of the others within 3 inches of the surface, but more than either within the next 9 inches. In it, as in the others, the percentage of moisture increased gradually from that point downwards, until obviously affected by the action of the pipe drains.

The soil of Plot 2, which had then been manured with 14 tons of dung per acre per annum for twenty-five years in succession, notwithstanding the greater requirements of the crop, retained rather more moisture than the unmanured soil within 3 inches of the surface; a result partly due, perhaps, but not wholly, to more shade. But, from that point downwards, doubtless influenced by the requirements of the crop, the dunged soil retained less at every stage (excepting the lowest) than the unmanured.

The soil of Plot 8, manured annually with mineral manure and ammonia-salts, and yielding pretty uniformly a heavier crop

TABLE V.—PERCENTAGES OF MOISTURE, in SUMMER and in WINTER, in the SOIL at different depths, of PLOTS in the EXPERIMENTAL WHEAT-FIELD differently manured.

Nos of Samples: 3 inches deep.	COLLECTED JULY, 1883.				COLLECTED JANUARY 6-7, 1889.				PLOT 3.			PLOT 2. ¹			PLOT 8a.		
	PLOT 3. Without Manure.	PLOT 2. Farmyard Manure.	PLOT 8a. Mineral Manure and Ammonia-salts.	Mean.	PLOT 3. Without Manure.	PLOT 2. Farmyard Manure.	PLOT 8a. Mineral Manure and Ammonia-salts.	Mean.	Without Manure.		Farmyard Manure.		PLOT 8a.				
									Collected July, 1888.	Collected Jan. 6, 1889.	Difference.	Collected July, 1888.	Collected Jan. 7, 1889.	Difference.	Collected July, 1888.	Collected Jan. 8, 1889.	Difference.
1	4.05	4.48	4.31	4.28	21.43	39.67	26.53	29.21	4.05	21.43	17.38	4.48	39.67	35.19	4.31	26.53	22.22
2	7.20	7.01	6.07(1)	6.76	24.54	35.62	22.93	27.70	7.20	24.54	17.34	7.01	35.62	28.61	6.07(1)	22.93	16.86
3	8.91	7.38	6.66	7.65	24.35	28.85	20.62	24.61	8.91	24.35	15.44	7.38	28.85	21.47	6.66	20.62	13.96
4	10.65	8.14	8.45	9.08	21.41	23.95	24.07	23.14	10.65	21.41	10.76	8.14	23.95	15.81	8.45	24.07	15.62
5	11.24	9.98	12.44	11.22	22.07	20.59	24.81	22.50	11.24	22.07	10.83	9.98	20.59	10.61	12.44	24.81	12.40
6	13.20	12.26	14.34	13.27	21.48	21.07	24.79	22.45	13.20	21.48	8.28	12.26	21.07	8.81	14.34	24.79	10.45
7	14.03	12.51	15.20	13.91	21.82	26.96	23.69	24.16	14.03	21.82	7.79	12.51	26.96	14.45	15.20	23.69	8.49
8	15.09	12.91	16.86	14.95	23.59	24.87	28.98	25.81	15.09	23.59	8.50	12.91	24.87	11.96	16.86	28.98	12.12
9	16.84	13.78	17.98	16.20	24.74	25.75	27.01	25.83	16.84	24.74	7.90	13.78	25.75	11.89	17.98	27.01	9.03
10	18.03	13.45	18.53	16.67	25.71	25.34	28.59	26.55	18.03	25.71	7.68	13.45	25.34	11.97	18.53	28.59	10.06
11	14.64	14.49	17.67	15.60	23.97	25.18	28.93	26.03	14.64	23.97	9.33	14.49	25.18	10.69	17.67	28.93	11.26
12	15.44	16.11	16.85	16.13	22.94	22.75	27.40	24.36	15.44	22.94	7.50	16.11	22.75	6.64	16.85	27.40	10.55
Mean	12.44	11.04	12.95	12.14	23.17	26.71	25.70	25.12	12.44	23.17	10.73	11.04	26.71	15.67	12.95	25.70	12.75

(1) There was an error in the determination in this case; and the figure given is calculated on the assumption that the amount of the moisture in the second 3 inches would probably bear about the same relation to that in the first and third 3 inches as the average in the cases of Plots 3 and 9.

than the dung, shows less moisture within the first 9 inches, and but little more within the next, or fourth 3 inches, than that of the dunged plot; also a total to that depth considerably less than the unmanured soil. From that point, however, there is a gradually increasing amount down to the range of the drains; notably more than in the dunged soil, and even more than in the unmanured, whose crop could only have withdrawn from it about one-third as much.

Supposing the three plots to have possessed exactly the same character of soil and subsoil, and to have contained the same amount of moisture to a given depth at the time of the commencement of active growth, we could well understand that, when the growth was nearly completed, the subsoil of the dunged plot, growing more than three times the crop, should contain less moisture than the unmanured subsoil. But, on the same suppositions, it would be difficult to account for the subsoil of Plot 8a, which grew even a larger crop than the dung, retaining not only more than the subsoil of the dunged plot, but more also than that of the unmanured plot. The differences between plot and plot as to percentage of moisture are, it is true, in some cases not great. But there is too much regularity and consistency in the results to admit of the supposition that the differences are due to errors arising from the unavoidable difficulties incident to the collection, weighing, and preparing the samples for drying, without some error of experiment affecting the estimation of the amount of water. The results relating to the soils and subsoils when supposed to be in a state of saturation will show, indeed, that the active growth of the crops probably did not commence with equal soil-supplies of moisture in the three cases.

The unmanured soil, when saturated, contained, to the depth examined, not much less than one-fourth its weight of water, and nearly twice as much as in the dry condition. The range of variation in the percentage was much less than in the dry soil; but, on the other hand, the order and degree of increase or decrease is much less regular in the wet soils. The top 3 inches contained rather less water than the second and third; otherwise, there would seem to be, at the time of saturation, more water near the surface, then a decreasing amount, and then a gradually increasing quantity, until the range of the drains is reached.

The dunged soil, with its vast accumulation of organic matter, and doubtless greater degree of disintegration, porosity, and power of absorption within some distance from the surface, is seen to hold about one and a half times as much water within the first 6 inches as the unmanured soil, or even as that manured

with mixed mineral manure and ammonia-salts. The third 3 inches, also, contains more than either; and the fourth more than the unmanured, and about as much as the artificially manured soil. The quantity continues to diminish to the fifth 3 inches, and then increases to about the level of the drains. To the total depth examined, the dunged soil contained more than a quarter of its weight of water, about $3\frac{1}{2}$ per cent. more than the unmanured, and about 1 per cent. more than the artificially manured soil.

The soil receiving mineral manure and ammonia-salts also retained more water within what may be called the staple than immediately below it. It then again increased in percentage of moisture, more or less regularly, until within the direct influence of the drains. It is to be observed, too, that, whether owing to a greater retentive power of the natural clay at that point, or more probably to the accumulation, and the action, of the constituents of the manures, or of their products of decomposition, rendering the clay more hygroscopic, the lower layers of the soil of this plot retained considerably more water when saturated than did the corresponding layers of either of the other plots. The amount of water to the total depth was about $2\frac{1}{2}$ per cent. more than in the unmanured soil, but not so much as in the dunged soil.

As might be expected, there are greater irregularities of increase or decrease indicated in the percentages of water at the different depths, among the results relating to the saturated, than among those relating to the dry soils. This may be due in part to accidental differences of permeability of the soil, and consequently to variation in the freedom of access of the percolating water, at the different points; but it is, doubtless, partly due to unavoidable error in the collection, weighing, and after-manipulation, of soil in so wet a condition.

Disregarding the irregularities, however, and interpreting the obvious direction of increase or decrease of moisture at the different depths, it is pretty clear that, down to a certain depth from the surface—which varied in the different plots according to the varying power of retention of the staple and immediately subjacent layers—the increased percentage of moisture was due to the comparatively recent rains. There was then reached the layers partially drained since the preceding rains, from which point downwards the percentage increased, until again reduced by the action of the pipe-drains.

Further, it is obvious that, by evaporation from the surface, and the consequent withdrawal by capillary action of water from below upwards on the one hand, and by the gradual descent, aided by the natural drainage of the chalk and the artificial

drainage of the pipes, on the other, what may be called the normal supply of water within the soil would, doubtless, at the commencement of active growth, be considerably less than that indicated by the percentages in the saturated soils. There is also good reason to suppose that, owing to the action of the manures, or their products of decomposition, within the soil and subsoil, the manured plots would retain more than the unmanured; and further, that whilst the effects of the dung would be chiefly to increase the retention by the upper layers, those of the artificial manures would be more characteristically to increase the amount retained by the lower layers.

This brings us to a comparison of the amount of water in each plot in the two conditions of unusual dryness and of saturation or abnormal wetness, as shown in the right-hand half of the Table V.

Referring first to the unmanured soil, there is seen to be a difference of more than 17 per cent. of moisture between the wet and dry conditions of the staple, or uppermost 6 inches of soil. The difference then diminishes, more rapidly at first, until, in the lower layers, it ranges from under 8 to about 9 per cent. There is an average of about $10\frac{1}{2}$ per cent. more water in the wet than in the dry soil to the total depth examined.

The difference between the saturated and the dry conditions of the various layers of the dunged soil is much more striking still: amounting to over 35 per cent. within the first 3 inches, to nearly 29 per cent. in the second 3 inches, to more than 21 per cent. in the third 3 inches, and to nearly 16 per cent. within the next, or fourth, 3 inches. It then lessens considerably, again increases, and again diminishes to within the range of the drain-pipes. The result is that, within the uppermost 12 inches of soil, there is an increase of about 25 per cent. of moisture in the wet as compared with the dry condition; or, taking the total depth of 36 inches, there is an increase of over $15\frac{1}{2}$ per cent.

The artificially manured soil also shows, almost throughout, greater difference in the amount of water retained in the two states than the unmanured, but less than the dunged soil. In the lower layers there are, as in the case of the dunged plot, some irregularities not satisfactorily explained. The final result, to the total depth of 36 inches, is an average of nearly 13 per cent. more water in the wet than in the dry condition.

It will be useful to compare the actual amounts of water per acre, in the different soils to the total depths examined, which the percentage results represent. Reckoning, as before, the soil in the dry state to weigh, exclusive of stones, an average of 1,000,000 lbs. per acre for each 3 inches of depth, we have 12,000,000 lbs. for the weight of the dry soil to the depth of

36 inches; and allowing one-eighth more for the wet soil, we have 13,500,000 lbs per acre for its weight to the depth of 36 inches. Adopting these figures, and the average percentage of moisture in the soil of each plot, we have the following amounts of water per acre on the respective plots in the two conditions:—

TABLE VI.

	July, 1868. Dry.	January, 1869. Saturated.	Difference.
Tons of Water, per Acre, to a depth of 36 inches.			
Plot 3.—Unmanured	666	1396	730
Plot 2.—With Farmyard Manure	591	1610	1019
Plot 8a.—With Mineral Manure and Am- monia-salts	694	1549	855
Tons of Water, per Acre, over (or under) Plot 3.			
Plot 2.—With Farmyard Manure	— 75	214	289
Plot 8a.—With Mineral Manure and Am- monia-salts	28	153	125

Thus we have on the unmanured plot 730, on the dunged plot 1019, and on the artificially manured plot 855 tons, more water per acre, to the depth of 36 inches, when the soils were saturated than when in the dry condition. As already said, the soils would not retain such an amount of moisture at the time of the commencement of active vegetation. But, by way of illustration, it may be stated that if they retained even two-thirds of the indicated difference prior to the commencement of the drought, and the commencement of active growth in 1868, the amount would be considerably more than would be required by the unmanured crop, and would supply a large proportion of that required by the manured crops, on the supposition that about 300 parts of water would be exhaled by the plants for 1 part of dry substance fixed by them. The soil-resources of moisture available to the growing crop would, however, doubtless extend beyond the depth to which the examinations refer. Then again, the amount of rain which actually fell during the period of active growth, though comparatively small, would, nevertheless, be not immaterial considered in relation to the balance of the requirements of the crops.

A very remarkable point connected with these results is, however, the difference in the amount of water retained per acre to a given depth by the soils of the different plots when saturated.

The unmanured soil and subsoil, comparatively little disturbed and disintegrated by the permeation and the decomposition of roots, and not at all by the action of manures, would offer less surface and absorb less water, and they are seen to retain less than those of either of the manured plots. The soil and subsoil of the artificially manured plot would be affected by the permeation not only of more roots, but of the solution of the manures or of some of their products of decomposition,—by the latter especially in the lower layers. But it is the dunged plot, with its vast accumulation of organic matter near the surface, and its finely divided and dissolved products of decomposition permeating to a greater or less depth beyond, and, doubtless, a considerable development of root, that is seen to possess the greatest power of retention of moisture, especially near the surface.

Taking the figures relating to the saturated soils as they stand, the artificially manured plot retained 153 tons, and the dunged plot 214 tons more water per acre, to the depth examined, than the unmanured—amounts which represent, respectively, about $1\frac{1}{2}$, and more than 2 inches of rain. Or, if we take the difference between the amounts retained in the dry and the wet conditions, the dunged soil shows a still greater excess of absorption when saturated, both compared with the unmanured, and with the artificially manured soils. Further, the details show that the dunged soil, when saturated, retained, within 12 inches of the surface, an excess of water which would be equivalent to about $1\frac{1}{2}$ inch of rain more than that held to the same depth on either of the other plots.

In connection with this interesting fact, it may be mentioned, that whilst the pipe-drains from every one of the other plots in the experimental wheat-field run *freely*, perhaps on the average four or five times annually, the drain from the dunged plot seldom runs at all more than once a year: indeed, it has not with certainty been known to run, though closely watched, since about this time last year. At first it was thought that there must be some stoppage, or some fault in the levels. Accordingly, the soil was opened in various places, but was found to be far from saturated down to the range of the drains. It was then concluded that the result was due to the greater power of absorption and retention of moisture by the dunged soil near the surface; and even supposing the figures above given should exaggerate the difference actually occurring, there would still be a wide margin remaining, sufficient to account for the fact of no water reaching the drains excepting under the influence of an unusually large and continued rainfall. Such a fact as the one here recorded is obviously of great interest and significance. Whether

the porosity of a clay soil be increased by the application of manure, by mechanical means, or by a combination of the two, its power to absorb and retain water, without being wet, and in an available state, will be proportionately increased, and the necessity for artificial drainage, at any rate on some soils, would be greatly obviated.

From the results adduced, it may safely be concluded, as already intimated, that the three plots would retain different amounts of water, due to the previous winter rains, at the time of the commencement of active vegetation in the spring. And although the actual amounts of excess indicated by the figures in Table VI. may not be true measures of the increased retention by the manured as compared with the unmanured soil, and although the excess at any one time may not be sufficient to meet the increased requirements of the manured crop, it must be supposed that the soils of higher retentive power would retain proportionally more of every heavy shower falling from time to time during growth; and hence may be accounted for the differences, not at first sight adequately explained, in the amounts of water retained by the different soils at the period when they had supported, and nearly carried to completion, such widely different amounts of crop.

Have we not, also, in the fact that the soil and subsoil, to a considerable depth, may frequently during the winter be saturated with water, a probable explanation, of part at least, of the less effect of a given amount of nitrogen applied in the autumn in the form of ammonia-salts, than of an equal amount supplied in the spring as nitrate of soda? For although the ammonia of the ammonia-salts is in great part absorbed by the upper layers of the soil, it is well established that a portion of the nitrogen supplied as manure in the form of ammonia becomes converted into nitric acid, and reaches the drains in the form of a nitrate; and it may be assumed that this action would, other things being equal, be the greater the greater the amount of water passing through the soil. Professor Voelcker, who has analysed many of the drainage waters collected at different times from the several plots in the experimental wheat-field at Rothamsted, has, moreover, found a greater amount of nitric acid in them the greater the amount of ammonia-salts applied as manure.

Another reason which may in part explain the frequent less effect of a given amount of nitrogen applied as ammonia-salts than of an equal amount applied as nitrate of soda, even when both are sown at the same time in the spring, may be that, as the nitric acid of the nitrate distributes more rapidly under the influence of rain than does the ammonia of the ammonia-salts,

so may the development of root be the more encouraged under the influence of the nitrate; and so, proportionately, will the plant gain greater possession of the soil, and consequently be able to avail itself of a wider range of both food and moisture within a given time. Further, from the results which have been recorded on the point in the foregoing pages, it would seem that when the nitrate is applied year after year on the same plot for many years in succession, the action on the soil and subsoil of its solution, or of that of the products of its decomposition, tends to increased disintegration, and to increased power of retention of moisture, and thus, again, to encourage a greater extension of root.

RESULTS RELATING TO THE GROWTH OF BARLEY.

Our next and last illustrations have reference to the growth of barley. This crop has been grown at Rothamsted for nineteen years in succession on the same land, without manure, with farm-yard manure, and with numerous artificial mixtures each year. The fluctuations in the amount of produce dependent on season, manure, and the continued growth of the crop, being greater than in the case of wheat, it would occupy too much space to follow up the same line of illustration as that adopted in regard to that crop; and it is the less necessary or desirable to do so, as we hope to report the whole of the results after the twentieth crop in succession has been harvested.

Referring to the influence of the variation of rainfall from year to year, it will suffice to say here that extremely low produce of barley was obtained with both a great excess and a great deficiency of rain during the months of active vegetation. The bad result with excess of rain was coincident with unusually low, or unusually high temperatures; and that with deficiency of rain with high temperatures. On the other hand, the highest amounts of produce were obtained with only moderate amounts of rain during the growing period, provided there were a favourable distribution of it, and a favourable adaptation of temperature. And whilst an excess of rain, during the growing months, is adverse to the favourable growth of both wheat and barley, a great deficiency of rain during that period is found to be, as would be anticipated, more adverse to the spring-sown barley than to the winter-sown wheat.

In the experiments on barley, equivalent amounts of nitrogen, as ammonia-salts and nitrate of soda respectively, have not been employed in conjunction with mineral manures from the commencement; but where they have been employed, each separately, without such admixture, a similar result is observed as with both

hay and wheat. That is to say, higher amounts of both corn and total produce have been obtained from the use of a given amount of nitrogen applied as nitrate of soda, than from that of an equal amount applied as ammonia-salts—both manures being in the case of barley sown in the spring.

In 1868 experiments were commenced in which nitrate of soda was used in conjunction with mineral manures, and below are given the results obtained in 1868, 1869, and 1870, with mixed mineral manure and 200 lbs. of ammonia-salts per acre per annum, compared with those of the same mixed mineral manure and 275 lbs. of nitrate of soda, which is estimated to contain about the same quantity of nitrogen as the ammonia-salts. As in the case of wheat, not the actual number of bushels measured, but the bushels of dressed corn calculated at an assumed uniform weight per bushel are given. For barley, 52 lbs. per bushel is taken.

TABLE VII.—Showing the effects on the Barley Crop of a given amount of Nitrogen as Ammonia-salts, compared with an equal amount as Nitrate of Soda.

	DRESSED CORN. (In bushels of 52 lbs.)		STRAW.		TOTAL PRODUCE. (Corn and Straw.)	
	Mineral Manure and Ammonia- salts.	Mineral Manure and Nitrate Soda.	Mineral Manure and Ammonia- salts.	Mineral Manure and Nitrate Soda.	Mineral Manure and Ammonia- salts.	Mineral Manure and Nitrate Soda.
	Bushels.	Bushels.	lbs.	lbs.	lbs.	lbs.
1868 ..	37	49	2333	2868	4311	5454
1869 ..	54 $\frac{3}{4}$	54 $\frac{1}{2}$	3853	4265	6701	7194
1870 ..	41 $\frac{1}{2}$	48 $\frac{1}{2}$	2090	2050	4287	4621
Mean	44 $\frac{3}{4}$	50 $\frac{1}{2}$	2759	3061	5100	5756

Here, then, we have again a similar result. There is, too, proportionately a greater increase with the nitrate, especially of corn, in the two drier and hotter seasons of 1868 and 1870—years, in fact, of summer drought.

The following Table shows the produce of barley without manure, with farmyard manure, and with mixed mineral manure and 200 lbs. ammonia-salts per acre, in 1868, and in 1870, the two recent years of summer drought; and also, under the same conditions as to manure, the average produce over the nineteen years of the experiment. As before, the number of bushels of dressed corn, reckoned at an uniform weight of 52 lbs. per bushel, is given. And, side by side with these records of produce, is given the

amounts of rain at Rothamsted, in April, May, June, and July, each year, those being the months of active growth of the barley crop.

TABLE VIII.

	DRESSED CORN. (In bushels of 52 lbs.)				TOTAL PRODUCE. (Corn and Straw).				RAINFALL AT ROTHAMSTED.				
	Without Manure.	Farmyard Manure.	Mineral Manure and Ammonia-salts.	Mean.	Without Manure.	Farmyard Manure.	Mineral Manure and Ammonia-salts.	Mean.	April.	May.	June.	July.	Total.
	Bush.	Bush.	Bush.	Bush.	lbs.	lbs.	lbs.	lbs.	Ins.	Ins.	Ins.	Ins.	Ins.
1868	11½	47½	37½	32	1902	5281	4311	3831	2·19	0·73	0·37	0·37	3·66
1870	13½	52½	41½	35½	1489	4949	4287	3575	0·46	1·33	0·98	1·12	3·91
Average, 19 Years, 1852-1870 ..	20	50½	48½	39½	2453	5856	5786	4698	1·72	2·36	2·43	2·37	8·88

As there has been a decline in the produce without manure during the second as compared with the first half of the period over which the experiments have extended, the difference indicated between the unmanured produce in the years of drought and that over the nineteen years will exaggerate the deficiency due to the deficient rainfall alone during the four growing months of the two years in question. On the other hand, the produce by farmyard manure has considerably increased during the latter half of the period, and hence the deficiency in the years of drought which the figures show for that manure is less than is due to the characters of the seasons alone. With the artificial manure the produce was, however, very much more nearly equal during the first and second halves of the total period, and the indicated deficiency in the years of drought probably more nearly represents that really due to the characters of the seasons in its case. With this manure there was a deficiency compared with the average, of 11 bushels of corn in 1868, and of 6½ bushels in 1870; or, of total produce, of 1475 lbs. in 1868, and of 1499 lbs. in 1870. There was not far from an equal total amount of rain during the four months in the two seasons; but whilst there was more than an average fall in April, 1868, and only about one-fourth the average fall in April, 1870, there was a greater deficiency in May, June, and July, 1868, than in the same months in 1870. The result was a greater deficiency of corn, but a less deficiency of straw, in 1868 than in 1870.

We are enabled to adduce more direct experimental evidence

showing the extent to which the barley-plant can avail itself of the stores of moisture within the soil, than that which was at command relating to wheat.

Before considering the results themselves, to which reference is here made, it will be well to describe briefly the circumstances under which they were obtained. With a view to the determination of what proportion of the rainfall passes to given depths in the subsoil, under different conditions of season, manuring, and cropping, a series of experiments has been commenced, for the cutting off, and the collection, of the drainage-water from the land at different depths—an essential condition being that neither soil nor subsoil should be disturbed. Leaving out of view for the present the questions of the influence of different manures, or of the growth of different crops, early in 1870 three plots of uncropped land, each of one-thousandth of an acre area, were selected, with a view of determining the amount of water passing below the depths of 20, 40, and 60 inches, respectively. The plan of operating was, to cut a sufficiently wide trench for men to work in, down one side of the plot, to a considerably greater depth than that at which the drainage was to be cut off. The plot was then carefully undermined and shored up at the depth decided upon, until a cast-iron plate, rather more than the length of the plot, 8 inches wide, and having small holes for the water to drain through, could be got in and fixed underneath. The plot was then further undermined, until another plate could be put in; and so on, until the whole was supported at the proper depth, without disturbance, by a perforated iron flooring, which finally was itself supported on three sides by brickwork, and on the fourth and across the middle by iron girders. The three as yet undisturbed sides of the plot were then trenched round; a $4\frac{1}{2}$ -inch brick and cement wall was built round the plot, resting on the projecting rim of the iron flooring below, and finished level with the surface above. The trench outside the wall was then filled in again. Thus, the exact area required was cut off from the surrounding soil by brickwork at the sides, and below, at the depth required, by a perforated iron flooring.

The field in which these *drain-gauges* were made, had grown wheat in 1869, and was sown with barley in March, 1870, and the drill by mistake was allowed to sow two rows of seed on the plots along one side of them. As the excavations proceeded, barley-roots were observed to have extended to a depth of between 4 and 5 feet, and the clayey subsoil appeared to be much more disintegrated, and much drier, where the roots had penetrated than where they had not. Accordingly, it was decided to make careful notes on the sections under the two conditions, and also to take samples of soil and subsoil to a depth below that at which roots

were traced, with a view to the determination of the amounts of moisture at the different depths in the two cases. Portions of the barley-ground and the fallow-ground, closely adjoining the drain-gauge plots, but undisturbed by the excavations in connection with them, were selected, and from each six samples, 6 × 6 inches superficies by 9 inches deep, that is, in all to a depth of 54 inches, were taken.

The following Table shows the percentages of moisture in the different samples, including that lost during their preparation, as well as that afterwards expelled at a temperature of 212° Fahr. :—

TABLE IX.—Percentages of Moisture in Uncropped and in Cropped Land, at different depths.

Samples collected June 27th and 28th, 1870.

Depth of Sample.				Fallow Land.	Barley Land.	Difference.
First	9 inches	..	..	20·36	11·91	8·45
Second	9 ..	..	..	29·53	19·32	10·21
Third	9 ..	..	..	34·84	22·83	12·01
Fourth	9 ..	..	..	34·32	25·09	9·23
Fifth	9 ..	..	..	31·31	26·98	4·33
Sixth	9 ..	..	..	33·55	26·38	7·17
Mean				30·65	22·09	8·56

Before commenting on these results, it should be stated that, ten days previous to the collection of the samples, about two-thirds of an inch of rain had fallen, and only three days before the collection about one-tenth of an inch; and hence, perhaps, may in part be accounted for the somewhat high percentage of moisture in both soils near the surface at that period of a season which was upon the whole one of unusual drought. Further, for a few days during the interval since the heavier rainfall, some soil, thrown out from the excavations near, had laid upon the spot whence the samples from the uncropped land were taken, and hence, again, may be accounted for part of the excess near the surface in the uncropped as compared with the cropped land.

The difference between the amounts of water retained at the depths examined by the uncropped and the cropped ground, at points only a few feet apart, is very striking; and that it should be greater in the upper portions of the subsoil, which had probably contributed more to the exigencies of the growing crop than the lower layers, is what would be expected. The percentage of water in the subsoil even of the cropped land was very high—indeed nearly as high at corresponding depths as in that in the

experimental wheat-field in January, 1869, when it was supposed to be in a state of saturation; whilst the amount in the subsoil of the uncropped land was not only considerably higher than in that of the cropped land, but considerably higher also than in that of the saturated wheat soil. We shall recur presently to the difference in the percentage of moisture in the soils and subsoils of the different fields which have been referred to, but must first direct attention to the more special application of the results now under consideration.

The following Table shows the number of tons of water per acre retained to the total depth of 54 inches, or $4\frac{1}{2}$ feet, by the uncropped and the cropped land, and the difference between the two. The upper line gives the amounts calculated according to the actual weights of the measured samples of soil (exclusive of stones), and the lower line the amounts, assuming that (exclusive of stones), the dry or barley soil would weigh 18, and the wet, uncropped or fallow soil $19\frac{1}{2}$ million lbs., to the depth of 54 inches:—

TABLE X.—Tons of Water per Acre to the depth of 54 inches, in Fallow Land, and in Land Cropped with Barley.

Samples collected June 27th and 28th, 1870.

	WATER PER ACRE.		
	Fallow Land.	Barley Land.	Difference.
According to experimentally determined weights of soil }	Tons.	Tons.	Tons.
	2875	1951	924
According to assumed average weights of soil }	2668	1775	893
Mean	2772	1863	909

On whichever basis the calculation is made, the indication is that there were about 900 tons less water per acre in the soil and subsoil, to the depth of 4 feet 6 inches, where the barley had grown than where the land was fallow. It may be that part of the excess in the uncropped land was due to the shelter from surface evaporation since the last preceding heavy rain, by the laying of soil upon it for a few days, as above referred to. But even supposing a liberal deduction on this account, the evidence would still point to the conclusion that there had been a higher rate of exhalation by the growing crop than 300 parts of water for every 1 part of dry substance fixed; for it may

safely be assumed that the dry matter of the crop at the time of the experiment would be under rather than over 2 tons per acre, which, at the rate of 300 parts to 1, would only account for an exhalation of 600 tons of water per acre. Further, since there was such a great difference in the percentage of moisture in the two cases at the lowest depth taken, it is only reasonable to conclude that the difference extended lower still.

To conclude, in reference to these particular experiments, it is clear that we have in the facts adduced sufficient evidence, and a striking illustration, of the enormous extent to which, in a time of drought, our crops may rely upon the supplies of moisture previously stored up within the soil. At the same time it cannot fail to be recognised how dependent must be the result upon the character of the soil and the subsoil with which the farmer may have to deal.

SUMMARY, AND GENERAL OBSERVATIONS.

Leaving detail, it will be of interest to summarise the results illustrating the difference of effect of the drought of the past year on the different crops, and also to bring together those relating to the amount of water retained by the soils and subsoils of the different fields, under the various conditions as to season, manuring, and cropping.

It has been already said that although the summers of both 1868 and 1870 were seasons of drought, yet, chiefly owing to the facts that the deficiency of rain commenced later, and the temperatures ruled higher in 1868, there was in reality considerable difference in the characters of the periods of growth of the two seasons, and in their consequent effects upon the different crops. To save space, however, we will confine attention here to the effects on the different crops of the more continued drought of 1870.

Table XI. shows the average annual produce obtained, under selected conditions as to manure, of hay, of wheat, and of barley; also the produce of each in 1870, and the deficiency compared with the average. In the case of the hay, the average is taken over 15 years, and in that of wheat and barley over 19 years. For simplicity of comparison, the produce is, for all three crops, given in lbs.; and the figures relating to wheat and barley represent the total produce, corn and straw together—which, of course, more clearly indicates the total amount of vegetable growth, compared with that of the hay, than the records of corn and straw separately would do.

Drought of 1870 and

TABLE XI.—Produce of Hay, Wheat, and Barley in 1870 compared with the average.

	Hay; 15 Years.	TOTAL PRODUCE, Corn and Straw.	
		Wheat; 19 Years.	Barley; 19 Years.
Without Manure.			
Average produce per acre per annum	lbs. 2391	lbs. 2398	lbs. 2453
Produce in 1870	644	2002	1489
Deficiency in 1870	1747	396	964
With Farmyard Manure.			
Average produce per acre per annum	4604*	6016	5856
Produce in 1870	1556	5092	4949
Deficiency in 1870	3048	924	907
With Mixed Mineral Manure and Ammonia-salts.			
Average produce per acre per annum	5794	6267	5786
Produce in 1870	3306	5836	4287
Deficiency in 1870	2488	431	1499

It is remarkable that, notwithstanding the great fluctuation in the amounts of produce of each of the three crops from year to year according to season, and also the difference in the degree in which each will vary from the average in one and the same season, still, when the average is taken over a considerable number of years, hay, wheat, and barley, are seen to yield *without manure* almost identically the same average weight of produce per acre per annum. On this point it should be mentioned that the second crop of grass is never removed from the land, being either consumed on it by sheep having no other food, or mown and left to rot as manure. The deficiency without manure, due to the drought of 1870, is seen to be 1747 lbs. of hay, 964 lbs. of barley (corn and straw), and only 396 lbs. of total produce of wheat. Thus, the deficiency was much the greatest in the hay; there being a reduction in its case by nearly three-fourths, in that

* For the hay crop, farmyard manure was only applied in the first 8 years; but the average produce is taken over the 15 years.

of the barley by scarcely two-fifths, and in that of the wheat by only about one-sixth, compared with average amounts.

For the hay-crop, farmyard manure was only applied during the first 8 years of the 15; but as the average produce was as great over the succeeding 6 years without the manure, as over the first 8 years with it, and as there was a heavier crop in 1869 than in any of the preceding 13 years, the deficiency in 1870 compared with the average, may be taken as at any rate mainly due to the drought, and but little to the cessation of the manuring. The figures as they stand show, as without manure, again, a much greater deficiency than in either wheat or barley; the crop amounting in fact to only one-third the average. Of total produce of wheat and barley, there is, with farmyard manure, again nearly the same average amount over 19 years in the two cases. The deficiency in 1870 compared with the average is also very nearly the same with the autumn-sown wheat and the spring-sown barley; amounting in each case to scarcely one-sixth. In the wheat the reduction is actually much greater, but in proportion to the average, only about the same as without manure; but in the barley it is actually less, though in proportion to the average very much less, than without manure. The greater power of retention of water which a dunged soil has been shown to possess in its upper layers, has doubtless much to do with the result.

With the artificial mixture, in the case of the hay and the wheat supplying 400 lbs., but in that of the barley only 200 lbs. of ammonia-salts per acre per annum, there is not the same uniformity in the average annual produce of the three crops; the wheat giving nearly 500 lbs. more gross produce than the hay with the same amount of ammonia applied, and the barley about the same as the hay, with only half the supply of ammonia-salts. The deficiency in 1870 amounts, in the hay to more than two-fifths, in the barley to rather more than one-fourth, and in the wheat to little more than one-fifteenth, compared with the average.

Thus, then, with a drought extending over the months of April, May, June, and July, the mixed herbage of permanent meadow land suffered, under the different conditions of manure in question, very much more than either wheat or barley; and the spring-sown barley suffered, both without manure and with the artificial manure, very much more than the autumn-sown wheat. With the farmyard manure, however, the barley would appear to have been as little adversely affected by the deficiency of rain during the period of actual growth as the wheat. We need not here again refer to the special conditions already explained, under which the hay crop was as little, or less, affected by the drought than the other crops.

The difference between the conditions of growth of the chiefly perennial (or biennial) plants composing the complex mixed herbage of permanent meadow land, and those of an annual, like wheat or barley, sown at a stated period of the year in arable land, and having a fixed, and in the case of barley only a limited time for distributing its underground feeders, and so availing itself of the resources of nutriment and moisture within the soil, are obviously very great.

The perennial, or biennial, character of most of the plants composing the mixed herbage, would seem at first sight to give the grass a great advantage over the corn crops. But observation shows, that although the immediately superficial layers of the soil may be more thoroughly penetrated by the roots of the perennial grasses than by those of either wheat or barley, yet it is only a very few of the former, encouraged to great predominance only under special conditions, that seem to get anything like the same possession of the lower layers of the soil as the two corn crops. Careful examination has also shown, and it is probably generally assumed, that the winter-sown wheat secures possession by its underground feeders of a more extended range and greater bulk of soil, and consequently is better able to avail itself of the supplies of food and moisture existing below a certain limited depth from the surface, than the spring-sown barley. The wheat-plant, indeed, has the advantage of making root, more or less according to season and manure, throughout the winter months, during periods of which, at any rate, the soil will be saturated with moisture; and in the case of moderately retentive and well drained soils, it will be able to establish its independence of rain falling during the period of active above-ground growth, very much more than will a spring-sown crop like barley.

But there are other points of distinction between the growth of the corn and the hay crops. Thus, most of the grasses, which comprise the greater proportion of the latter, flower earlier than the wheat or the barley; and the mixed herbage is cut by, or before, the end of June, when very little, if any of it, has arrived at the degree of ripeness in which the corn crops are cut. These, on the other hand, are not only allowed fully to ripen, but direct experiments made at Rothamsted upon wheat have shown that a very large proportion, probably about half, of the total dry vegetable substance, or of the total carbon of the crop, is fixed in it under the influence of the greater power of the sun's rays after the time at which the hay crop is usually cut.

These facts are obviously an element in the explanation of another fact, to a certain extent commonly recognised, and which a careful comparison of the results of the field experiments at

Rothamsted, with the records of the conditions of heat and moisture under which the crops have been grown, brings clearly to view—namely, that, as compared with the hay crop, the corn crops are not only less dependent on the amounts of rain falling during the period of active vegetation, but more on a relatively high degree of temperature during that period. This is more strikingly the case when wheat is grown by means of readily soluble mineral and nitrogenous manures, than when it is grown without manure, or with farmyard manure. Without manure the produce is comparatively more dependent on the amount of certain constituents brought down by the rain, or rendered available by its means from the stores of the soil itself; and it would seem that where farmyard manure is employed, a considerable amount of rain is required during the early growing period to aid its decomposition, and so to set free, distribute, and render available, its fertilising constituents. In the case of the artificial manures, on the other hand, some of the most active fertilising constituents are supplied in a much more soluble form, and require a less amount and continuity of rain for their solution and distribution throughout the pores of the soil within a given range.

It is seen, then, that several reasons concur to render corn crops less dependent on the fluctuations in the amount of rain falling during the period of active vegetation and accumulation of substance than is the hay crop growing under otherwise parallel conditions as to soil and manure. It is quite intelligible, too, that the autumn-sown wheat, with its much longer time for the formation and distribution of root, and its tendency to develop proportionally more in the lower and proportionally less in the upper layers of the soil, than the spring-sown barley, should be less adversely affected than the latter by a deficiency of rain during the period of active above-ground growth.

Table XII. brings together at one view the percentage amounts of water retained by the soils and subsoils of the different fields, under the various conditions as to season, cropping, &c. The results so summarised relate to samples collected as under:—

1. From the experimental wheat field, just before harvest, 1868; mean of three plots differently manured.
2. From the experimental wheat field, in January, 1869, when the land was supposed to be saturated; mean of the same three plots differently manured.
3. From uncropped land, near the end of June, 1870.
4. From land cropped with barley, closely adjoining the uncropped land; samples collected at the same date, end of June, 1870.

5. From permanent meadow land, in July, 1870, after the removal of the crop; mean of three plots differently manured.

TABLE XII.—Summary of Percentages of Moisture in Soils and Subsoils from different Fields, and under different conditions as to Season, Cropping, &c.

Depths of Samples.	EXPERIMENTAL WHEAT FIELD.		BARN FIELD.		PERMANENT MEADOW LAND.
	Samples collected, July, 1868; Mean of Plots 3, 2, and 8a.	Samples collected, Jan. 6th and 7th, 1869; Mean of Plots 3, 2, and 8a.	Samples collected, June 27th and 28th, 1870.		Samples collected, July 25th and 26th, 1870; Mean of Plots 3, 2, and 14.
			Uncropped Land.	Land Growing Barley.	
First 9 ins.	6·23	27·17	20·36	11·91	11·99
Second 9 „	11·19	22·70	29·53	19·32	11·77
Third 9 „	15·02	25·27	34·84	22·83	17·11
Fourth 9 „	16·13	25·65	34·32	25·09	19·32
Mean 36 „	12·14	25·19	29·76	19·79	15·05
Fifth 9 „	..	..	31·31	26·98	20·67
Sixth 9 „	..	..	33·55	26·38	21·49
Mean 54 „	..	..	30·65	22·09	17·06

The special application of the detailed results having been already fully considered, attention must be confined here to the more general indications only of the foregoing summary.

In the first place, it should be observed that all three fields have a subsoil of reddish yellow clay, resting upon chalk, at a varying depth, but of not many feet from the surface. All, therefore, have good natural drainage; and it is very seldom that any water collects in the furrows, and then only for a very few hours. The experimental wheat field is, however, pipe-drained at a depth of about 30 inches, and at a distance of about 25 feet from drain to drain.

It is of interest to observe that there is no wide difference in the amount of water retained at corresponding depths in the experimental wheat-field in July 1868, when the crop was nearly at maturity, and in the permanent meadow land in July 1870, after the removal of the hay crop. The percentages are, however, rather lower in the drained land; which, at the time, had probably supported a higher average amount of produce also.

Towards the end of June 1870, the undrained arable land, which then carried a crop of growing barley, representing perhaps from 1½ to 2 tons of dry substance fixed, retained only about the same amount of water near the surface as the meadow land in July 1868; but, lower down, it held considerably more than either the drained wheat land in July 1868, or the undrained meadow land in July 1870.

It is remarkable that the uncropped and undrained land, though retaining much less water within 9 inches from the surface, from that point downwards retained, in June 1870, considerably more at every stage than the drained wheat soil in January 1869, when the drains were running, and the land was supposed to be saturated. From this comparison, it is obvious that no safe conclusion can be drawn from the percentage of water in the subsoil of the uncropped but undrained land, as to the probable amount retained by the subsoil of the drained land at the commencement of active vegetation in the spring. The amount retained in the subsoil of the uncropped and undrained land is indeed enormous; but the comparison of it with that in the adjoining cropped land shows clearly enough that it was readily available for the purposes of vegetation. In reference to this latter point, the fact of the good natural drainage by the chalk must not be overlooked.

There is, upon the whole, general consistency in the results brought together in Table XII. It may, perhaps, safely be concluded that, notwithstanding the natural drainage by the chalk, the pipe-drains had contributed to reduce the percentage of moisture retained by the subsoil of the experimental wheat field, to the depth examined; but that they had, at the same time, rendered the clay more permeable by roots, and the water that was retained more readily available. The evidence is, at any rate, very striking as to the degree in which, in a time of drought, our crops are enabled to rely upon the water previously accumulated within the subsoil—provided the latter be of sufficient depth, of sufficient retentive power, and at the same time sufficiently permeable.

Before concluding, it will be well to call attention to a very important bearing of some of the results adduced. Assuming, as we may be allowed to do for the sake of illustration, that a good crop of hay, wheat, or barley, will probably exhale not less, and perhaps more, than 700 tons of water per acre during growth, we still have only about 7 inches of rain, out of an average annual fall of say 25 inches, thus directly disposed of by the growing crop; and, taking the amount retained by the soil itself as practically a constant quantity from year to year, there remains to be disposed of by evaporation from the surface, and by passage into the drains or otherwise beyond the reach of the roots of the crop, an average of about 18 inches of rain annually, equivalent to more than 1800 tons of water per acre.

How much of this large quantity of water passes off by evaporation from the surface of the soil itself, inducing by capillary action the withdrawal of water, carrying with it, it may be, essential plant-food, from the lower to the upper layers of the soil?—or, how

much passes downwards, carrying in solution any manurial matters in excess of the quantity which can be absorbed and retained within the pores of the soil and the upper layers of the subsoil?

These questions cannot be so satisfactorily answered in regard even to any particular soil, or season, as is desirable; and could they be so, the answers would vary greatly with variations of soil and season. As already stated, direct experiments are now in progress at Rothamsted with the view of acquiring useful data on this subject. With regard to the results hitherto obtained, it may be remarked that, from September 1st to December 31st, 1870, that is, commencing after the unusual drought of the preceding summer, it was found that, out of a rainfall of about 10·5 inches within the same period, about 50 per cent. had passed below a depth of 20 inches, about 40 per cent. below 40 inches, and about 20 per cent. below 60 inches from the surface. Calculation further showed that, even supposing there were some accumulation during August, still, a very large proportion of that which did not so pass, would be required to bring the previously very dry soil to the point of saturation—judging this requirement from the results which have been already given bearing upon the point. That is to say, as would be expected, a comparatively small proportion of the rainfall was evaporated at that season of the year. Much more would, of course, so disappear taking the whole year round; the quantity varying considerably with the characters of the soil and the season.

Towards the end of the last century, Dr. Dalton* devised an apparatus for the determination of the proportion of the rainfall which passed off from the soil by drainage, and by evaporation, respectively. It consisted of a cylinder, 10 inches in diameter, 3 feet deep, open at the top, and closed at the bottom; but having one small exit tube near the top, and another near the bottom, for the escape of water into bottles placed to receive it. The vessel was filled with earth, and sunk into the ground level with the surface, one side being left exposed for access to the bottles. He continued the experiment for three years, 1796-7-8, and found the drainage to average, over that period, 25 per cent., and the evaporation to be, therefore, equal to 75 per cent. of the rainfall. This was exclusive of any evaporation of dew, but inclusive of that resulting from vegetation, as the surface of the soil became, after the first year, covered with grass; a circumstance which, however, Dr. Dalton considered immaterial.

For eight years, 1836-1843, Mr. Dickinson, of Abbott's Hill, King's Langley, Herts,† experimented with a modification of

* Mem. Lit. Phil. Soc. of Manchester, vol. v., part 2.

† 'Journal of the Royal Agricultural Society,' vol. v.

Dalton's apparatus. The cylinder he employed was 12 inches in diameter, and 3 feet deep, but provided at that depth with a perforated bottom, and a receptacle beneath for the collection of the water; and there was an arrangement of tubes for the escape, and measurement, of the drainage water. Grass was grown on the surface of the soil in the cylinder. The drainage would doubtless be more free in the experiments of Mr. Dickinson than in those of Dr. Dalton; and the results, over 8 years, showed, with a less rainfall, a larger actual amount of drainage; the latter representing $42\frac{1}{2}$ per cent., and the evaporation, therefore, only $57\frac{1}{2}$ per cent. of the rainfall. This amount included, of course, the exhalation due to vegetable growth.

From results obtained by gauging the flow of water from pipe-drains, it has been concluded that a still larger proportion of the rainfall passes off by evaporation than that indicated by the experiments of either Mr. Dickinson or Dr. Dalton. But results obtained by deducting the amount passing through drains from the total rainfall may be judged to be quite untrustworthy, from the fact that, before the pipe-drains in the experimental wheat field had passed any water at all in the autumn of last year, the *drain-gauges* already referred to had indicated that, of the rain which had then fallen since the 1st of September, nearly 25 per cent. had passed below 20 inches, nearly 10 per cent. below 40 inches, and nearly 4 per cent. below 60 inches from the surface. It is clear, therefore, that the amount of water passing through artificial drains may be no measure whatever of the total quantity passing below the reach of the roots of growing crops.*

In the admitted defect of satisfactory evidence from which may be deduced the probable average amount of evaporation from the surface of the soil independently of vegetation, we will assume, by way of illustration, that, taking the average of many

* It was not until after this Paper went to press for the *Journal*, that we recollected the experiments of Maurice, Gasparin, and Risler, relating to this subject, and therefore make brief reference to them here. M. Maurice, experimenting at Geneva, over two years, 1796 and 1797, sought to measure the evaporation from the soil by means of a cylindrical iron vessel filled with earth, the changes in the weight of which he determined daily during that period. His results indicated an amount of evaporation corresponding to about 61 per cent. of the rainfall, which latter averaged over the two years about 26 inches per annum. ('Bibl. Britan. de Genève: Sciences et Arts,' t. i.) M. Gasparin, experimenting in a somewhat similar way at Orange, in the south of France, found the evaporation so determined to amount, in the two years 1821 and 1822, to about 80 per cent. of a rainfall of about 28 inches per annum. ('Cours d'Agriculture,' t. ii. p. 116.) M. Risler, again, at Calèves, near Nyon, Switzerland, by gauging drains 1·2 metre (about 4 feet) deep, in a very compact and impervious subsoil, estimated the evaporation over the two years, 1867 and 1868, to amount to about 70 per cent. of a rainfall which averaged over the period about 41 inches per annum. The land was cropped, as usual, during the period of the experiment; so that the amount of evaporation indicated includes that due to vegetable growth. ('Archives des Sciences de la Bibliothèque Universelle,' Sept., 1869.)

soils and seasons, three-fourths of a total rainfall of 25 inches will pass off by the combined action of evaporation from the surface of the soil itself, and of the exhalation due to the growth of a good crop of hay or corn. On this supposition there would still remain more than 6 inches of rain, equivalent to more than 600 tons of water per acre, annually passing downwards, and carrying with it more or less of fertilising matters.

Fortunately, some of the most important mineral constituents of soils and manures are, in the case of the heavier soils at any rate, almost wholly retained by them within the range of the roots of our crops. Nitrogen, whether supplied in the form of ammonia-salts or nitrates is, however, much less completely so retained; being, in whichever state supplied, carried off in greater or less quantity in the drainage water, chiefly in the form of nitrates. According to results obtained independently by Professor Frankland and Professor Voelcker, on the analysis of drainage water from the experimental wheat-field at Rothamsted, that collected during the winter, from land manured in the autumn by an amount of ammonia-salts supplying 82 lbs. of nitrogen per acre, may contain from 2.5 to 3 parts, or even more, of nitrogen, as nitrates and nitrites, per 100,000 parts of water. Assuming that only 2.5 parts of nitrogen were so carried beyond the reach of roots for every 100,000 parts of water passing downwards, there would still be, for every inch of rain so passing, a loss per acre of between 5 and 6 lbs. of nitrogen, supplied in manure at a cost of not much less than 1s. per lb.

The above estimate of quantity must be understood to be adopted only provisionally, and by way of illustration. It is, however, a sufficiently near approximation to what must happen in the case of many soils and seasons at any rate, to show the very great importance of further investigating the reactions of various descriptions of nitrogenous manure on different descriptions of soil, and of determining the best modes, and the best periods of the year, for the application of such manurial matters, so as to reduce the loss by drainage to a minimum. This subject is now receiving attention at Rothamsted.

Rothamsted, January, 1871.

[*Extracted from the JOURNAL of the ROYAL HORTICULTURAL
SOCIETY, vol. iii., 1871.*]

NOTES ON

"CLOVER-SICKNESS."

BY

J. H. GILBERT, PH.D., F.R.S., F.C.S.

LONDON :
REPRINTED BY SPOTTISWOODE & CO., NEW-STREET SQUARE.
1895.

Having being informed by Mr. Berkeley that it was his intention to make some observations on the subject of "Clover-sickness" at the Meeting of the Scientific Committee to-day, and having been requested by him to state briefly the results of the attempts made at Rothamsted to grow clover more frequently on the same land than custom recognizes as practicable, I have, in conjunction with Mr. Lawes, drawn up a summary statement of the plan and results of the experiments, partly in the form of a short abstract of previously published accounts, but bringing the record up to the present date.

Among the causes which have been assigned for clover-sickness may be mentioned :—

Exhaustion of the soil.

The growth of parasitic plants which strike their roots into the clover and exhaust its juices.

Destruction by insects.

The injurious influences arising from the matter excreted by the roots of a former crop, or from the decay of the roots themselves.

The growth of the young plant under the shade of a corn-crop.

With regard to the last supposition, which, in a letter in the "Gardener's Chronicle" of May 13th, Mr. Berkeley seems disposed to adopt, it may be stated that during the period of twenty-three seasons over which our experiments on the subject have now extended, clover has more frequently been sown alone than with a corn-crop, and the failures have been as signal under those as under the usual conditions.

The experiments on the growth of clover with many different descriptions of manure were commenced in 1849, and, with the occasional interposition of a corn-crop or fallow, have been continued up to the present time. The land is divided into three main divisions, each of which comprises a series of six plots.

Series 1.—The plots of this series have received no carbonaceous, and scarcely any nitrogenous manure since the commencement. On the other hand, some of them have received much more of both potass and sulphuric acid, and more phosphoric acid, but all less, and generally considerably less, lime and magnesia than have up to this date been taken off in the crops.

Series 2.—These plots have all received a considerable amount of both carbonaceous and nitrogenous manures, supplying, on the average, about half, but in some cases more than half, as much of both carbon and nitrogen as have been taken off in the crops. Of potass and sulphuric acid, some of the plots have received considerably more, of phosphoric acid rather more or not much less, of lime very much more, but of magnesia in all cases less than were yielded in the crops.

Series 3.—The plots of this series have also received a considerable quantity of both carbon and nitrogen, but all of them less than those of series 2. Some of them have received more, or not much less, potass, magnesia, and phosphoric acid, considerably more sulphuric acid, and very much more lime than were contained in the crops.

These very summary comparative statements relate to the whole period from 1849 up to the present time ; and the observations which follow will for the most part have reference to the same period. But it should be observed that many of the plots which now show an excess of removal over supply of certain constituents did not do so at the time of the first failures. It will presently be seen that failure commenced after growing the crop a second time with the interposition of only a single wheat-crop. This was the case notwithstanding that at that time, and even later, on some of the plots more of all constituents (excepting perhaps carbon) had been supplied in manure than taken off in the crops. It was obviously, therefore, not merely a question of supply or exhaustion, using the terms in the same sense as we should do in reference to wheat or barley, for example. One object of the plan of experimenting followed was, therefore, to give time for the proper *soil-digestion*, or distribution of the constituents already directly supplied, or which might otherwise exist within the soil, in case this might be the condition needed.

As with other *leguminous* crops, the general result has been that mineral constituents applied as manures (particularly potass)

considerably increased the early crops ; whereas ammonia-salts had little or no beneficial effect, and were sometimes injurious. It may be added that even up to the present time the beneficial effects of long previous applications of potass are apparent whenever there is any growth at all.

To go into a little more detail : The crops were throughout very heavy in the first year (1849), especially on the plots of series 1, with mineral, but with no carbonaceous or nitrogenous manure. In the autumn of that year wheat was sown, and in the spring of 1850 Red Clover. In 1851 small cuttings were taken ; and in 1852, though the crops were not heavy, there was by no means a failure. Since that time, however, all attempts to grow clover year after year on the same land have failed to give anything like a full crop, or a plant which would stand the usual time on the ground. Small cuttings were obtained in the autumns of 1855 and 1859 from seed sown in the spring of those years, and small cuttings, but rather heavier than in the former cases, in 1865 (June and August) from seed sown in 1864.

On the plots of series 1, seed has been sown ten times during the twenty-three years of the experiment, namely, in 1848, 1850, 1853, 1854, 1855, 1859, 1864, 1868, 1869, and 1870. In seven out of the last eight trials the plant has died off in the winter or spring succeeding the sowing the seed ; and at the present time the land is again ploughed up, the plant having entirely died off in the spring, now three years in succession. The plots of series 2 and 3, on the other hand, though previously sown as frequently as those of series 1, were not sown in either 1868 or 1869, but were ploughed and left fallow, and only sown again in 1870 ; and they carry, at the present time, a rather thin, but fairly healthy crop ; whilst, as already said, the plants from the seed sown at the same time on series 1 entirely died away in the spring.

The difference between the conditions of the plots of series 1, resulting at the present time in entire failure, and those of series 2 and 3, affording at least comparative success, may be briefly summarized as follows :—

In the first place, in the cases of the utter failure, seed was sown, and plants came up, in 1868 and 1869, as well as in 1870, that is in three consecutive seasons ; whereas in those of the partial success none was sown between 1864 and 1870.

So far as regards manure, the chief distinctions are—that where there is entire failure, neither carbon nor nitrogen has

been supplied in manure ; but where there is partial success both have been supplied, but neither of them in amount equal to that of their removal in the crops. With regard to mineral constituents, the conditions of series 1, resulting in failure, are—a considerable excess of supply of both potass and sulphuric acid, and a considerably greater excess of both than on either series 2 or series 3 ; no essential difference as to phosphoric acid ; a greater deficiency of magnesia than in either series 2 or series 3 ; and lastly, a considerable loss of lime, whereas on the plots of series 2 and 3, very much more lime has been supplied in manure than taken off in the crops.

It would appear, therefore, that if the failure on series 1, compared with series 2 and 3, be due to the greater exhaustion of certain constituents, it must be of either carbon, nitrogen, magnesia, or lime. On this point it may be mentioned that the excess of carbon removed in the crops, over that supplied in the manure, has been in no case nearly approaching that which may take place with impunity in the case of either wheat or barley. On the other hand, the average annual removal of nitrogen has been considerably greater on all the plots of series 1, but generally less on those of series 2 and 3, than happens with either wheat or barley grown without nitrogenous manure ; it has, however, been considerably less than in experiments on the mixed herbage of grass-land where no nitrogenous manure has been employed.

Again, taking of course the whole period, the exhaustion of magnesia has been generally greater, and that of lime considerably greater, than has occurred in the experiments on the continuous growth of wheat or barley. So far, then, as the result depends on mere amount, rather than on condition or distribution of constituents, it would appear to be connected with a deficiency of nitrogen, of magnesia, or of lime, or of more than one of them.

Having regard to the question of the condition and distribution of the constituents, in 1864 a portion of the land of series 1 was trenched 2 feet deep, one third of the manure being mixed with the layer from 24 to 16 inches, one third from 16 to 8 inches, and the remainder from 8 inches upwards. Superphosphate of lime, and salts of potass, soda and magnesia, the first two in very large quantity, were used ; and nitrate of soda, which is a much more favourable form of application of nitrogen

for leguminous crops than ammonia-salts, and which distributes more rapidly, was also liberally applied. Owing to the character of the season, the mechanical condition of the land was very unfavourable after this treatment ; and, although many years have now elapsed, and the excess of constituents supplied is in some cases considerable, the plant has died off as completely on the plots so treated as elsewhere.

In view of these failures in the field, it is a fact of much interest that in 1854 Red Clover was sown in a garden only a few hundred yards distant from the experimental field, on soil which has been under ordinary garden-cultivation for probably two or three centuries, and it has every year since shown very luxuriant growth ; and after resowing four times, namely, in 1860, 1865, 1868, and 1870, during that period, there is at the present time not only no indication of failure, but, on the contrary, very luxuriant growth. It may be added, by way of illustration merely, that if the produce on these small garden plots be calculated to the acre, it would represent a removal in seventeen years, at the rate of more than $1\frac{1}{2}$ ton of lime, nearly $\frac{1}{2}$ ton of magnesia, more than a ton of potass, nearly $\frac{1}{2}$ ton of phosphoric acid, and about $1\frac{1}{2}$ ton of nitrogen per acre, without the supply of any of either during the period of the experiment.

Lastly, in the winter of 1867-68, small portions of the land of series 1 were dug, some to the depth of 9 inches, some to the depth of 18, some to the depth of 27, and some to the depth of 36 inches, and sown to the respective depths with different manurial mixtures ; supplying in some cases very large amounts of potass, soda, lime, magnesia, phosphoric acid, sulphuric acid, nitrate of soda, &c. From other similarly sized plots, the soil was removed to the depth of 9, 18, and 27 inches respectively, and replaced by soil from the same depths from the garden border, on a portion of which clover had been grown successfully since 1854, as above referred to. In April 1868, clover was sown over the whole of these small plots, as well as over the rest of the land of series 1 not so treated ; but the plant for the most part died off during the winter. The same portions were resown in April 1869, and small quantities of clover were cut in September of that year ; but the plant again died off in the winter. In April 1870, clover was again sown, this time in conjunction with harley ; but the plant again died off during the past winter and early spring. This result should not, however, at present be

taken as absolute proof of failure of the manurial conditions supplied on the various small plots; for, not only was the summer of 1870 one of extraordinary drought, but where the manures were applied at the different depths specified, the land may not yet have recovered a favourable mechanical condition, and where the natural soil was replaced by that from the garden border, the plants, being luxuriant compared with any around them, were more a prey to woodpigeons, rabbits, and game. The whole of these small plots are now resown, and those of the garden-soil are entirely enclosed, both around and above, by galvanized wire netting.

The general result of the experiments in the field is—that neither organic matter rich in carbon as well as other constituents, nor ammonia-salts, nor nitrate of soda, nor mineral constituents, nor a complex mixture, supplied as manure, whether at the surface or at a considerable depth, has hitherto availed to restore the clover-yielding capabilities of the land.

On the other hand, it is clear that the garden-soil supplied the conditions under which clover can be grown year after year on the same ground for many years in succession.

The results obtained on the garden-soil seem to show that what is called “clover-sickness” cannot be due to the injurious influence of excreted matters upon the immediately succeeding crop.

That the clover crop frequently fails coincidently with injury from parasitic plants, or insects, cannot be disputed; but it may be doubted whether such injury should be reckoned as the cause, or merely the concomitant and an aggravation of the failing condition.

If, then, it be decided that the cause of failure is not destruction by parasitic plants or insects, nor injury from excreted matters, nor the shade of a corn-crop, and that it is to be looked for in exhaustion of the soil, there will still remain several open questions. Is it exhaustion of certain organic matters rich in carbon, of nitrogenous food, or of mineral constituents? Again, is there an actual exhaustion of the substances in question, or only an unfavourable condition of combination, or, so to speak, of *soil-digestion* of them, for the accumulative and assimilative requirements of leguminous plants? Or, is there only an unfavourable distribution of them within the soil, considered in relation to the extent and character of the root-range of the crops?

These various points cannot be considered in detail within our present limits ; but a few brief observations may be made in reference to them by way of explanation and suggestion.

The results obtained on the garden-soil are, of course, consistent with the supposition that there was in the field-soil a want of some of the ultimate elements of the crop. They are also consistent with the assumption that it is not merely requisite that the constituents should be present in the state of combination and of distribution available for other descriptions of crop, but that it is essential for the healthy development of the clover-plant, that the constituents should have undergone a certain digestion, so to speak, within the soil ; or that certain constituents should have become more distributed than is necessary for the cereal crops. On either supposition the result may be dependent on the proper supply of carbon, of nitrogen, or of mineral constituents. Thus, in garden-soil, liberally dunged for centuries, there would be a great accumulation of all constituents. A large amount of both carbon and nitrogen compounds would have undergone considerable, if not as complete change as could take place within the soil ; and their products, as well as mineral constituents, would be widely distributed.

Although, taking the whole period, carbon has been removed in the crops from all the plots in larger quantities than it has been supplied to them in manure, experience with other descriptions of crop would not lead to the supposition that the failure could be due to a deficiency of that constituent provided it were taken up by the Leguminosæ exclusively as carbonic acid, yielded by the atmosphere, or by the decomposition of organic matter within the soil. If, however, it were the case that some plants, clover, for example, required for healthy development at certain stages of their growth a portion of their carbon to be presented them in other compounds—organic acids more complex than carbonic acid, in combination, it may be, with ammonia, or with fixed bases—we could then easily understand that, under ordinary circumstances, a certain period of time might be requisite for the formation and accumulation of a sufficient amount of the compounds in question. It would also be intelligible that there should be a great accumulation of such compounds in the soil where dung had been liberally used for centuries. A fact of another kind, which is at any rate consistent with the view here assumed, is, that the ashes of the Leguminosæ we cultivate con-

tain a large proportion of carbonate indicating, possibly, that the fixed bases had been taken up in combination with a combustible organic acid. Again, another fact in accordance with the view is, that although a Leguminous crop assimilates two, three, or more times as much nitrogen over a given area as a Gramineous one, the direct application of ammonia-salts, so effective with the latter, is more frequently injurious than beneficial to the former within the season of their employment; though, after some time has elapsed, some beneficial effects can be observed, apparently due to the previous supplies. An obviously possible explanation of this is, that organic acid salts of ammonia have been formed.

On the other hand, nitrate of soda, though not a reliable manure for Leguminous crops, as it and ammonia-salts are for the Gramineæ, is certainly much more beneficial to them than are ammonia-salts; and, it may be, that it is not until the ammonia has in great part been converted into nitric acid, and the resulting nitrates become widely distributed throughout the pores of the soil and subsoil, that the Leguminous plant attains sufficiently active and vigorous growth, and acquires sufficient possession of the soil, to render it independent of its many enemies—whether in the form of animal or vegetable parasites, or of climatic vicissitudes which slacken its vitality, and render it an easier prey to its animal or vegetable enemies.

On the supposition that the favourable condition of the nitrogen is that of ammonia in combination with an organic acid, we have to conclude that that condition, even if favourable, is at any rate not essential for the Gramineous crop, or that the distribution of the compounds in question is such as to render them not so readily available for the Gramineous as for the Leguminous plants. Supposing, however, that the required condition be the oxidation of the ammonia and the wider distribution of the nitrogen in the form of nitrates than would take place so long as it remained as ammonia, that portion of the nitrogen which is supplied in manure for the Gramineæ, and which, owing either to unfavourable combination, or unfavourable distribution, within the soil, is not recovered in the increase of the immediate crop, becomes gradually oxidated and more widely distributed, and the Leguminous crop, alternating with the Gramineous one, and gathering from a more extended or different range of soil, in its turn leaves a residue, or allows the

accumulation, of assimilable nitrogen within the range of collection of the crops which succeed it. On this view, not only does the growth of the Leguminous crop serve to arrest the loss of nitrogen by drainage as nitric acid, by bringing up again much of that which had passed in that condition into the lower layers of the soil ; but there is obviously provided one important element at least in the explanation of the beneficial effects of alternating Leguminous with Gramineous crops in rotation.

Again, the nitric acid would, most probably in great part, be in combination with lime, which is the base occurring in large proportion in the ash of our Leguminous crops ; and supposing nitrogen were taken up by the plants as nitric acid, chiefly in combination with lime, but partly with potash or other bases, we should, in that fact, have an element in the explanation of the occurrence in the ashes of the Leguminosæ of so much fixed base, and especially of lime, not in combination with a fixed acid ; and we should, so far, to a less extent require the aid of the assumption that the bases in question had been taken up from the soil as ready-formed organic acid salts.

The above considerations are of interest not only with reference to the results obtained in the highly manured garden-soil, but also in connexion with the facts of the entire failure in the field at the present time where neither carbonaceous nor nitrogenous manures have been supplied, and lime has been the most exhausted, and of the partial success where carbonaceous and nitrogenous manures have been to a considerable extent supplied, and lime has been added in great excess.

It is obvious that the time that would serve for the formation and distribution of the organic acid salts, or of the nitrates, would also serve for the soil-digestion, and distribution, of mineral constituents.

To conclude, in regard to the conditions of failure and partial success in the field at the present time, it may be remarked that on some portions of the land where there is the complete failure, considerably more of those mineral constituents which most characteristically increase the growth of a healthy clover crop in the land in question, have been supplied than taken off in the crops.

This has not, however, been the case with the nitrogen on any portion of the experimental land ; though, as already said, the exhaustion of it has nowhere been so great as in experiments on mixed herbage, including perennial Leguminous species. On

the other hand, where there is at the present time a fairly healthy, but only small crop growing, the application of those mineral constituents which most increase a healthy plant has been considerably less, but that of nitrogen has been greater than where there is the total failure. Nevertheless, on the portions where there has been the most liberal supply of those mineral constituents—potass, for example—there is at the present time considerably more growth than where there has been no such supply.

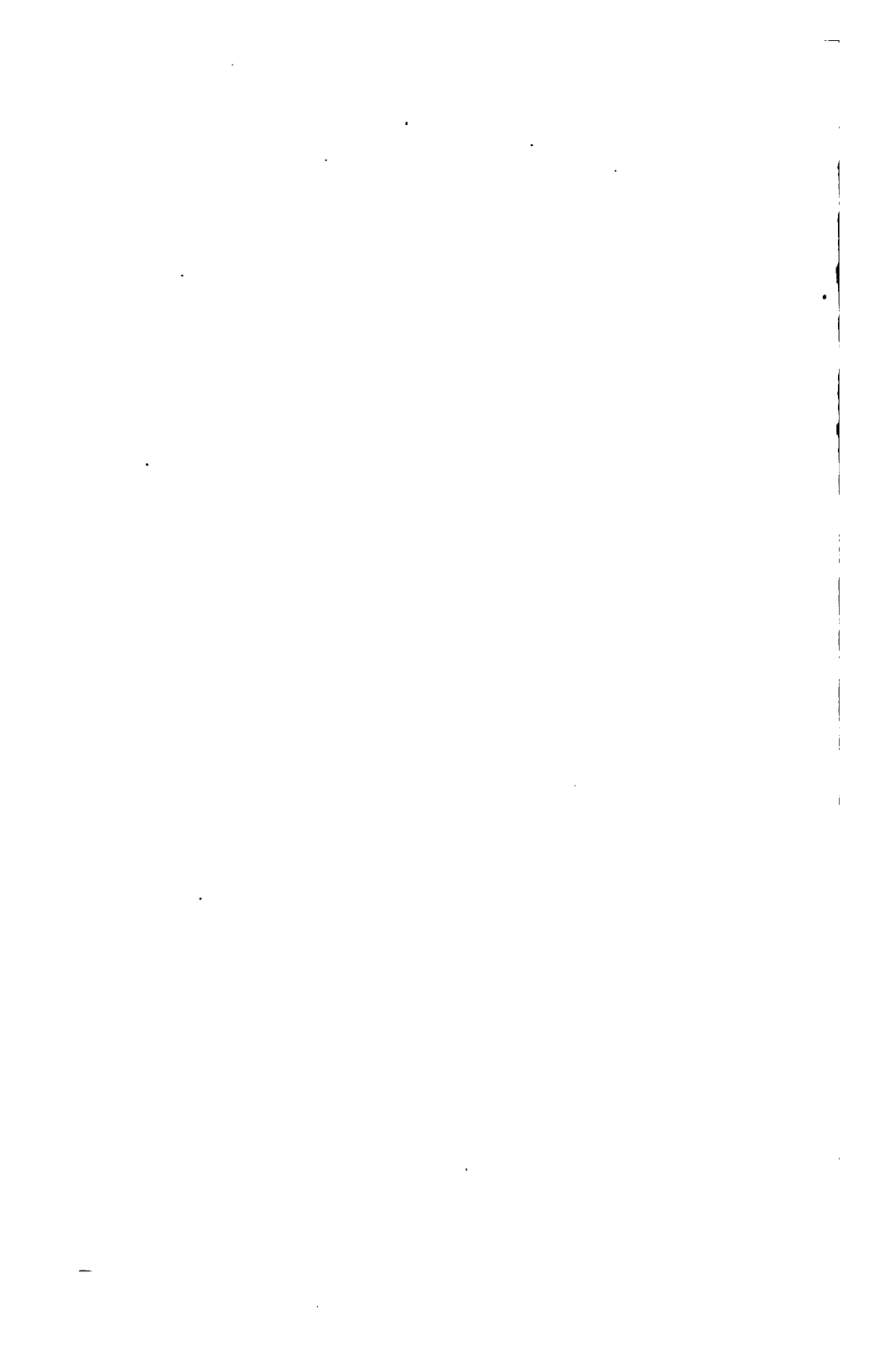
Lastly, in regard to the attempts made to supply the fertilizing matters at a considerable depth below the surface, it is admitted that, for a time at least, the resulting physical condition of the soil and subsoil was not satisfactory; though, even at present, indications are wanting that beneficial effects may eventually follow.

This brief record of many failures may be concluded by a quotation from a paper on the subject published by Mr. Lawes and myself some years ago:—

“When land is not what is called ‘clover-sick,’ the crop of clover may frequently be increased by top-dressings of manure containing potass and superphosphate of lime; but the high price of salts of potass, and the uncertainty of the action of manures upon the crop, render the application of artificial manures for clover a practice of doubtful economy.

“When the land is what is called ‘clover-sick,’ none of the ordinary manures, whether ‘artificial’ or natural, can be relied upon to secure a crop.

“So far as our present knowledge goes, the only means of insuring a good crop of Red Clover is to allow some years to elapse before repeating the crop upon the same land.”



REPORT OF EXPERIMENTS
ON THE
GROWTH OF BARLEY

FOR TWENTY YEARS IN SUCCESSION ON THE
SAME LAND.

By J. B. LAWES, Esq., F.R.S., F.C.S.;

AND

J. H. GILBERT, Ph.D., F.R.S., F.C.S.

LONDON:
PRINTED BY WILLIAM CLOWES AND SONS, STAMFORD STREET,
AND CHABING CROSS.

1873.

FROM THE
JOURNAL OF THE ROYAL AGRICULTURAL SOCIETY OF ENGLAND,
VOL. IX.—S.S. PARTS I. AND II.

Pages 5-79 (and APPENDIX-TABLES) in Part I., February, 1873.
Pages 79-178 in Part II., October, 1873.

CONTENTS.

INTRODUCTION.		PAGE
Statement of the question		5
General plan of the Experiments		7
General description of the Manures employed		9
The Field Results :—Division of the subject		11
SECTION I.—QUANTITY AND QUALITY OF THE PRODUCE OBTAINED IN EACH OF THE 20 SEASONS.		
Introductory observations; general bearing of the results		12
Characters of each of the 20 seasons, and amount and characters of the Produce of each season, 1852–1871		17
Produce in the least, and in the most, productive seasons of the twenty ..		71
Average annual produce over the first 10, the second 10, and the total period of 20 years		76
SECTION II.—AVERAGE ANNUAL PRODUCE BY EACH DESCRIPTION OF MANURE EMPLOYED.		
Introductory observations		79
Without Manure		80
By Farmyard-manure		84
By Mineral Manure alone		88
By Ammonia-salts alone, or Nitrate of Soda alone		93
By Ammonia-salts, or Nitrate of Soda, with Mineral Manure		99
By Rape-cake		111
Summary		113
SECTION III.—AMOUNT OF AMMONIA IN MANURE (OR ITS EQUIVALENT OF NITROGEN IN OTHER FORMS) REQUIRED TO YIELD A GIVEN INCREASE OF GRAIN (AND ITS PROPORTION OF STRAW).		
Introductory observations		116
The experimental results		117
Summary		124

**SECTION IV.—EFFECTS OF THE UNEXHAUSTED RESIDUE FROM PREVIOUS
MANURING UPON SUCCEEDING CROPS, LOSS OF CONSTITUENTS BY
DRAINAGE, AND SOME ALLIED POINTS.**

	PAGE
Introductory observations	125
Effects of the unexhausted residue of Nitrogen applied as Ammonia-salts or Nitrate of Soda	126
Nitrogen recovered, and not recovered, in increase of Produce, for 100 supplied in Manure	132
What becomes of the Nitrogen supplied in Manure and not recovered in the increase of Produce?	135
Accumulation of Nitrogen within the Soil	136
Loss of Nitrogen by Drainage	137
Effects of the unexhausted Residue from previously supplied Mineral or Ash-constituents	151
Summary .. .	154

**SECTION V.—RESULTS OBTAINED IN OTHER FIELDS, AND UNDER OTHER
CONDITIONS AS TO CROPPING, MANURING, &c.**

Introductory observations	156
Three years of Barley after ten years of Turnips	156
Barley in Four-course Rotation	161

**SECTION VI.—SUMMARY AND GENERAL CONCLUSIONS, SHOWING THE
PRACTICAL BEARINGS OF THE RESULTS.**

Summary and general Conclusions	166
Practical application of the Results	177

APPENDIX—TABLES.

TABLE	I. Manures per acre per annum	179
"	II. Bushels of dressed Corn per acre	180
"	III. Weight per bushel of dressed Corn, lbs.	182
"	IV. Offal Corn per acre, lbs.	184
"	V. Total Corn per acre, lbs.	186
"	VI. Straw (and Chaff) per acre, cwts.	188
"	VII. Total Produce (Corn, Straw, and Chaff) per acre, lbs.	190
"	VIII. Increase by Manure, of total Corn, per acre, lbs.	192
"	IX. Increase by Manure, of Straw (and Chaff), per acre, lbs.	194
"	X. Increase by Manure, of total Produce, per acre, lbs.	196
"	XI. Proportion of offal Corn to 100 dressed Corn	198
"	XII. Proportion of total Corn to 100 Straw (and Chaff)	200

R E P O R T

OF

EXPERIMENTS ON THE GROWTH OF BARLEY

FOR TWENTY YEARS IN SUCCESSION ON THE
SAME LAND.

IN volumes viii. xii. and xvi. of the first series of the 'Journal of the Royal Agricultural Society of England,' we gave some account of experiments on the growth of Wheat year after year on the same land; in volume xxv. (1864), we published a detailed Report on the growth of the crop, without manure, and with different descriptions of manure, for twenty years in succession on the same land; and the twenty-ninth crop has now been harvested. In volume xviii. (1857), results on the growth of Barley, under somewhat similar conditions of manuring, for six years in succession on the same land, were given. Those experiments have been continued up to the present time, and are still in progress; and we are now enabled to record the results obtained with barley, as already with wheat, over twenty consecutive seasons.

Barley is, at any rate through the greater part of England, if not throughout Scotland and Ireland, the second in importance of the cereal grains we cultivate; in some localities, indeed, it is of first importance. It is a prominent element in the well-known four-course rotation, and is more or less prominent in almost every rotation throughout the greater part of the British Isles. Moreover, it is supposed that the characters and the condition of land under which it can be advantageously cultivated are greatly limited, and that its market value is much influenced, by certain fiscal arrangements. From various points of view, therefore, exact knowledge of the quantity and quality of the produce it yields, on a soil of a given description, but under a great variety of well-defined conditions as to manuring, and in seasons of very various characters, cannot fail to be of great practical interest.

The conditions of growth of barley, are, in some respects, very similar to those of wheat; but in others they are very different. Thus, as a rule, wheat is sown in the autumn, but barley not until the spring; and it has, therefore, much less time for the distribution of its roots, and for getting possession of the stores within the soil. Again, the descriptions of soil which are the most suitable for the growth of wheat, are generally not equally

well adapted for the growth of barley. Hence, apart from the importance attaching to the barley-crop as a prominent and independent element in most of our rotations, the question of the degree in which the requirements and results of its growth are similar to, or different from, those of its botanical ally—wheat (both belonging to the same natural family, the *Graminaceæ*), is one of very considerable interest, both practical and scientific.

Little less interesting would it be, not only to compare the results obtained with winter-sown wheat and spring-sown barley, but to include in the comparison the likewise spring-sown oats, the third in importance among the corn-yielding plants of the graminaceous family cultivated in temperate climates. But the experiments on the continuous growth of oats have, as yet, only extended over a very few seasons; so that at present we can only incidentally and imperfectly make reference to them. There is, however, already sufficient indication that the results will, in due time, have considerable, both independent and comparative, value.

The first experimental wheat-crop, in the field in which the 30th in succession is now growing, was harvested in 1844; and, in the spring of 1845, about 10 acres, in an immediately adjoining field, were appropriated to somewhat similar experiments on barley. Owing, however, to the great amount of labour and attention that would be required in following them up with sufficient accuracy and detail, it was decided to rest satisfied for a time with the first year's clear indications. These were sufficient to show the great similarity, in some important respects, between the requirements and the conditions of growth of the two closely allied crops. But very much still remained to be learnt, and especially in regard to the equally important distinctions between the requirements of the two crops.

Much also was still wanting in the way of direct experimental evidence bearing upon the then opening "Mineral Theory" controversy; respecting the issues of which very few English agricultural readers are not, by this time, overwhelmingly satisfied. Indeed, the universal practical experience of British agriculture during the last quarter of a century of experiment, discussion, and general improvement, has entirely confirmed the views we have held on the subject, and published in the 'Journal'; whilst, our distinguished opponent has not only sought to associate with the term "Mineral Theory," a meaning totally different from that which attached to it in the well-known controversy, but, under cover of a change of nomenclature, has claimed, as consistent with his own theory, views directly at variance with those he formerly maintained, and in the main accordant with the facts and conclusions which we have brought forward in opposition to the distinctive views of his earlier writings. Some illustrations bearing upon these points will be incidentally given further on;

but considering how settled are the opinions now generally held on the subject in this country, and how changed are those of the author of the "Mineral Theory," it would be out of place to devote so much of either time or space to its discussion in our introductory remarks as has been suitable on former occasions. Still less will it be necessary to discuss the results obtained with barley very prominently in their relation to the points that were in controversy in the early years of the progress of the experiments.

The experiments on barley were re-commenced in 1852, and the twentieth crop in succession was harvested in 1871. The land selected was a portion of that immediately adjoining the experimental wheat field, on which the preliminary trials in 1845 had been made. About $4\frac{1}{2}$ of the 10 acres were devoted to the purpose. The general character of the land is much the same as that of the wheat field, namely, "a somewhat heavy loam, with a subsoil of raw, yellowish red clay, but resting in its turn upon chalk, which provides good natural drainage." The wheat field has, however, as a matter of experiment, been artificially drained, but the barley field has not.

The custom of the locality, in the case of land of similar quality, is to take the barley crop after roots fed off by sheep. But it will be readily understood from the above description of the soil, that it is too heavy for this to be done with advantage in wet seasons. Nevertheless, good crops, both in point of quantity and quality, are so grown, on such land, in favourable seasons, and may, as a rule, be relied upon when barley is taken, not after folding, but after another corn crop.

The questions to be solved by the experiments on barley may be stated in the same terms as were employed in introducing the Report of the results obtained with wheat:—"What are the grain-yielding capabilities of such land?—what its powers of endurance?—in what constituents, or class of constituents, does it soonest show signs of exhaustion?—and how far will the answers arrived at on these points in reference to it, accord with, or be a guide to, those which would apply to any large proportion of the arable land of Great Britain when farmed in the ordinary way, with rotation?"

THE FIELD EXPERIMENTS ON BARLEY.

The previous cropping of the land set apart in 1852 for the continuous growth of barley was as under:—

1847, Swedish turnips, with farmyard manure and superphosphate (the roots carted off).

1848, Barley.

1849, Clover.

1850, Wheat.

1851, Barley, with sulphate of ammonia.

It had thus already grown two corn crops in succession, and was, therefore, agriculturally speaking, in a somewhat exhausted condition for the after-growth of grain, and would, in the course of ordinary practice, be re-manured before growing another crop. It was, therefore, in a suitable state for testing the effects of different manures upon the crop, and for showing, by the results, in what constituents, or class of constituents, the soil had, by the previous cropping, become practically the most deficient.

The area of $4\frac{1}{2}$ acres was divided into 24 nearly square plots; most of which were exactly one-fifth of an acre each, but the remainder somewhat less. Two plots were left unmanured; one was manured every year with farmyard-manure; and others with different manures, which, respectively, supplied certain constituents of farmyard manure, separately or in combination.

We here repeat, in answer to objections recently reiterated (this time in Germany), that we believe comparative results obtained by growing crops year after year on the same land, without manure, and with different manurial constituents, singly and in admixture, are far better calculated to indicate in what constituent, or constituents, the soil is relatively deficient, so far as the available supply for the crop to be grown is concerned, than what is generally understood as an analysis of the soil. On this point it may be well to quote a paragraph from our paper on the growth of Wheat for twenty years in succession on the same land:—

“Our conclusion, as indicated in former papers, and frequently expressed in answer to the objections of chemical friends who had not paid special attention to the applications of chemistry to agriculture, was, that far more had yet to be done in determining the chemical and physical qualities of soils in relation to the atmosphere, and to manurial substances exposed to their action, as well as in perfecting methods of analysis, before comparative analyses could aid us much in deciding upon the relative productiveness of different soils, to say nothing of the still more difficult problem of estimating, by such means, the condition of fertility or exhaustion of one and the same soil at different times. Of late years very much has been done in these departments of investigation; still, as recent discussions abundantly show, far too little is even yet known of what a soil either is or ought to be, in a chemical point of view, to render the results of the analysis of soils directly applicable to the solution of questions such as those we had in view in our inquiry. But if our knowledge of the chemistry of soils should progress as rapidly as it has during the last twenty years, the analysis of a soil will ere long become much more significant than it is at present.” (*Journal of the Royal Agricultural Society of England*, vol. xxv. p. 98.)

In accordance with the views here indicated, we have from time to time, from 1846 up to 1870, taken samples of the soils

and subsoils of our different experimental plots, until the collection now comprises about 300 specimens. In a large proportion of these the nitrogen, and in some the carbon, has been determined. Some have been experimented upon at Rothamsted in other ways, and some at Munich by Baron Liebig's son, Hermann von Liebig, who requested to have samples for examination; and the whole are carefully prepared and preserved, with a view to more complete investigation whenever time will permit. Reference will be made further on to some of the results that have been obtained. It is, then, not the chemical examination of soils on a systematic plan, and by methods carefully arranged and well adapted for the solution of specific questions, that we have regarded as unimportant; but it is the mere determination, in accordance with antiquated theoretical ideas, of the ultimate percentage composition of a soil, without due regard to the condition in which the constituents exist, and by methods which do not give sufficiently accurate or comparative results, that we have considered of little value. In the mean time let us see whether the synthetic, as distinguished from the analytic method of enquiry, will not give as important and conclusive evidence as to the conditions and requirements of growth of barley, as it has done in regard to other crops.

General Description of the Manures employed.

It has already been said that the selection of manures for the experiments on barley was, in many respects, the same as that adopted for those on wheat. In reference to this point it may be useful, by way of illustration, to show the probable average amounts of certain constituents in what may be taken as fairly corresponding crops of wheat and barley. For this purpose we will assume a produce per acre of—

Wheat, 30 bushels, of 60 lbs. per bushel = 1800 lbs., and

3000 lbs. straw, = 4800 lbs. total produce;

Barley, 40 bushels, of 52 lbs. per bushel = 2080 lbs., and

2500 lbs. straw, = 4580 lbs. total produce;

which will contain, approximately, the following constituents:—

	In Corn.		In Straw.		In Total Produce.	
	Wheat.	Barley.	Wheat.	Barley.	Wheat.	Barley.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Nitrogen	32	33	13	12	45	45
Phosphoric acid ..	16	17	7	5	23	22
Potass	9.5	11.5	20.5	18.5	30	30
Lime	1	1.5	9	10.5	10	12
Magnesia	3.5	4	3	2.5	6.5	6.5
Silica	0.5	12	99.5	63	100	75

It will be observed that most of the above constituents (which, in the sense that they are those which are the most likely to become deficient in the soil, may be said to be the most important constituents of the two crops) occur in nearly equal amounts in the total produce of either. The most prominent exceptions are, that the total barley crop would remove rather more lime, but considerably less silica, than the wheat crop. But, looking to the grain alone, the barley is seen to remove considerably more of silica, and rather more of each other constituent, than the wheat. Therefore, in cases in which the grain only is sold, and the straw is returned to the land in due course as manure, the eventual loss to the soil would be upon the whole greater, especially in silica, by the growth of such a crop of barley than of such a crop of wheat. In the experiments now to be considered, however, both corn and straw are always entirely removed from the land.

In Germany, it has recently been urged against the plan of our experiments, that the amounts of the different constituents applied as manure, for the different crops, have no direct relation to the amounts which are annually removed from the soil in the crops. We freely admit that this is the case. We at the same time maintain that, with the existing knowledge at the time of the arrangement of the experiments—nay, even with present knowledge, or rather ignorance—of the reactions of the different manurial substances within the soil, of the consequent distribution and state of combination within it of the constituents they supply, and of how far, accordingly, they are available for the crop to be grown, it would be the merest pedantry to apply only so much of each constituent as had been, or was expected to be, removed in the crop. We have, indeed, followed the plan supposed by our critics, in isolated cases, with the view of testing the validity of the assumptions upon which it is founded, and the result has been most signal failure, so far as the amount of the resulting crop is concerned.

Both the description, and the amounts, of the manures actually employed for the barley, are recorded in full in the folding Table, No. XXIV. (facing p. 80), and in Appendix-Table I., p. 179. They are in many respects the same as were adopted in the wheat experiments; and, as in those experiments, the most available and convenient forms in which the different constituents occur in the market have been selected. Thus (omitting from the enumeration those supplied in farmyard manure and rape-cake), the different "mineral" * or ash-constituents were supplied as follows:—

* With regard to the use of the term "mineral" see vol. xxiv., pp. 506-8 (foot-note), and vol. xxv., p. 101 (and context), of the 'Journal'; also vol. xvi. pp. 447-8, and context.

Potass—as sulphate of potass.

Soda—as sulphate of soda.

Magnesia—as sulphate of magnesia.

Lime—as sulphate, phosphate, and superphosphate.

Phosphoric acid—as bone-ash, mixed with sulphuric acid in quantity sufficient to convert most of the insoluble earthy phosphate of lime into sulphate and soluble superphosphate of lime.

Sulphuric acid—in the phosphatic mixture just mentioned; in sulphates of potass, soda, and magnesia; in sulphate of ammonia, &c.

Chlorine—in muriate of ammonia.

Silica—as artificial silicate of soda.

Other constituents have been supplied as under:—

Nitrogen—as sulphate and muriate of ammonia; as nitrate of soda; in farmyard manure; in rape-cake.

Non-nitrogenous organic matter, yielding by decomposition carbonic acid, and other products—in farmyard manure, in rape-cake.

The artificial manure or mixture for each plot is ground up, or otherwise mixed, with a sufficient quantity of soil and turf-ashes to make it up to a convenient measure for equal distribution over the land. The mixtures so prepared are, with proper precautions, sown broadcast by hand; as it has been found that the application of an exact amount of manure, to a limited area of land, can be best accomplished in that way.

THE FIELD RESULTS.

The results obtained with barley will be arranged and discussed under separate heads, adopting much the same division of the subject as in the report on the experiments with wheat, but following a somewhat different order of illustration. Accordingly, they will be considered in Sections as under:—

I.—Quantity and quality of the produce obtained, by different descriptions of manure, in each of the twenty seasons; with summary statements of the characters of each season.

II.—Average annual produce obtained over many years in succession, by each description of manure employed.

III.—Amount of ammonia in manure (or its equivalent of nitrogen in other forms), required to yield a given increase of grain (and its proportion of straw), according to the quantity applied per acre, to the available supply of mineral constituents within the soil, and to the characters of the season.

IV.—Effects of the unexhausted residue from previous manuring

(both nitrogenous and mineral) upon succeeding crops, loss of constituents by drainage, and some allied points.

V.—Comparison of the results with those obtained in other fields, and under other conditions as to cropping, manuring, &c.

VI.—Summary, and general conclusions, showing the practical bearings of the results.

On this plan, the consideration in Section I. of the fluctuations in the quantity and quality of the produce due to season, and in Section II. of the average results obtained by the different manures over many seasons, will bring before the reader the main facts of the field experiments as such. He will then be in a position to appreciate the great practical importance, and the great scientific interest, of the questions discussed in Sections III. and IV., and to judge of the value of the evidence brought to bear upon them.

SECTION I. QUANTITY AND QUALITY OF THE PRODUCE OBTAINED IN THE DIFFERENT SEASONS.

In the following comments on the quantity and quality of the produce obtained in each of the twenty seasons separately, the observations on the characters of the seasons themselves are founded, partly on Mr. Glaisher's quarterly reports, partly on our own, and partly on other records; and they, as well as those relating to the crops of the country, may be taken as in the main applicable, so far as such brief and general statements can be, to a considerable portion of the Midland, Eastern, and South-Eastern districts of England. It may be further explained that, to aid the study of the characters of the several seasons, and with a view to the statements given of them, Tables have been arranged showing the actual climatic statistics of the seasons, and also others of their indices, showing the relative order of the characters registered, comparing season with season.

A little consideration will show that this branch of the subject is not less intricate than it is important; and it can of necessity be but incidentally and incompletely treated of within the limits of such a paper as this. Thus, it is obvious that different seasons will differ almost infinitely at each succeeding period of their advance, and that, with each variation, the character of development of the plant will also vary, tending to luxuriance, or to maturation, that is, to quantity, or to quality, as the case may be. Hence, only a very detailed consideration of climatic statistics, taken together with careful periodic observations in the field, can afford a really clear perception of the connection between the ever fluctuating characters of season and the equally fluctuating

characters of growth and produce. It is, in fact, the distribution of the various elements making up the season, their mutual adaptations, and their adaptation to the stage of growth of the plant, which throughout influence the tendency to produce quantity or quality. It not unfrequently happens, too, that some passing conditions, not indicated by a summary of the meteorological registry, may affect the crop very strikingly; and thus the cause will be overlooked, unless careful observations be also made, and the stage of progress, and tendencies of growth, of the crop itself at the time, be likewise taken into account.

Having regard to these considerations, and to the well-known fact—which is only their practical consequence—that those characters of season which are very unfavourable for land in poor condition, may be favourable to land in high condition, and *vice versa*, such a selection from the results obtained in each year has been made as it was thought would best illustrate the influence of season on the productive effects of characteristically different conditions of manuring; and for each of the twenty seasons the produce of the same plots is taken for illustration.

In explanation of the abbreviated descriptions of the manures given in the Tables, it may be stated that—

The “farmyard manure” was made in the open yard, and did not contain the dung of animals highly fed on purchased food.

The “Mixed Mineral Manure” was composed, per acre per annum, of—

200 lbs. sulphate of potass (300 lbs. the first 6 years).	
100 lbs. sulphate of soda (200 lbs. the first 6 years).	
100 lbs. sulphate of magnesia.	
200 lbs. bone-ash.	} superphosphate of
150 lbs. sulphuric acid, sp. gr. 1.7	
	lime.

The “Ammonia Salts” consist of an equal mixture of the sulphate and muriate of ammonia of commerce.

For the sake of easy reference, and for comparison with the produce in each individual season, there is given in Table I., on the following page, the particulars of the average produce over the 20 years, on each of the plots selected for illustration in this Section.

In passing, the significant fact may here be noted, that, over a period of 20 years in succession, ammonia-salts alone gave an average, per acre per annum, of 5 bushels more corn, and of 4 cwts. more straw, than the mixed mineral manure alone. Again, the ammonia-salts and mixed mineral manure together gave an average annual produce of about 19 bushels more corn, and 14 cwts. more straw, than the mineral manure

TABLE I.—Average Quantity and Quality of Barley per Acre, per annum, on selected plots. Twenty Years, 1852–1871.

Plots.	MANURES, PER ACRE, PER ANNUM.	AVERAGE PRODUCE, &c., PER ACRE PER ANNUM.					
		Dressed Corn.		Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn to 100 Straw.
		Quantity.	Weight per Bushel.				
		Bushels.	lbs.	lbs.	Cwts.	lbs.	
1 O	Unmanured	20	52·3	1133	11½	2454	86·6
7	14 Tons Farmyard Manure	48½	54·3	2768	28½	5933	88·5
4 O	Mixed Mineral Manure, alone ..	27½	53·4	1550	14½	3162	96·4
1 A	200 lbs. Ammonia-salts, alone ..	32½	52·1	1840	18½	3919	89·2
4 A	Mixed Mineral Manure, and ..	46½	54·0	2630	28½	5817	83·2
	200 lbs. Ammonia-salts						
	Mixed Mineral Manure, and ..	49½	53·4	2813	32½	6443	79·5
4 A A	400 lbs. Ammonia-salts first 6 years						
	200 lbs. Ammonia-salts next 10 years						
	275 lbs. Nitrate Soda last 4 years ..						
	Mixed Mineral Manure, and ..	47½	53·6	2698	29½	6002	83·0
4 C	2000 lbs. Rape-cake first 6 years						
	1000 lbs. Rape-cake last 14 years ..						

alone; but only about 14 bushels more corn, and 10 cwts. more straw, than the ammonia-salts alone.

There can be no doubt, therefore, that in this, in an agricultural sense, already corn-exhausted soil, the available supply of nitrogen was much more readily exhausted than the available supply of mineral constituents, so far as the requirements for the growth of barley are concerned.

It may be stated at the outset then, that the results obtained with barley, so far show general accordance with those on wheat; and that those with both crops are entirely inconsistent with the "Mineral Theory," according to which it was maintained—"that the supply of ammonia is unnecessary for most of our cultivated plants, and that it may be even superfluous, if only the soil contain a sufficient supply of the mineral food of plants, when the ammonia required for their development will be furnished by the atmosphere."

We need hardly say that the sharp distinction, the direct antithesis, between the terms "mineral" and "ammonia," as used in the above sentence, was habitually adopted by Baron Liebig in his earlier agricultural writings*; in fact, the "Mineral Theory" which was so long in controversy, can hardly be more clearly stated in so few words, than in those just given, written by himself.

* For a few additional illustrations see foot-note pp. 506-8, vol. xxiv. part 2 of the 'Journal of the Royal Agricultural Society of England.'

Notwithstanding this, what does he say now? He ignores his former arguments and views. He repudiates the obvious meaning of the terms he employed. He attributes to his opponents ignorance of the fact that, in a special scientific sense, ammonia-salts are mineral substances. He says—"All the materials constituting the food of our cultivated plants belong to the mineral kingdom." And—"Sulphate of ammonia and sal-ammoniac are mineral" Thus, ammonia is now claimed as a mineral manure, instead of antithetic to it, as throughout his earlier writings; and, accordingly, he claims as consistent with his "Mineral Theory," any beneficial effects from the use of nitrogenous manures. He would, indeed, have it supposed by the rising generation of readers, and if possible established for the future, that the "Mineral Theory" of Agriculture which has been in controversy is the "Mineral Theory" of vegetation in general, according to which, as distinguished from the so-called "Humus Theory," all the food of plants is mineral.

Having made these fundamental changes, without acknowledgment of either change or error, he endeavours to divert the attention of his modern and future readers from his earlier works and editions, and insinuates that the error has been on the side of his opponents. Thus, in 1870, in the course of a disquisition on the claims of *truth* in scientific inquiry, he speaks of his long forbearance in reference to the opposition to his views on the theory of fermentation, the sources of muscular power, the formation of fat, &c., and, in agricultural chemistry, on the laws of the nutrition of plants and animals. But, he goes on to say, there is for every one a limit, when it becomes his duty again to contend for that which he holds to be true, and this is reached, when error has gained the victory, and scarcely a doubt is expressed that it may be the truth. Then, with more special reference to the controversy with ourselves, he proceeds—

"In this way it happened to my views on agriculture, on the causes of the exhaustion of soils, and the conditions of the restoration of their fertility; in the 16 years which elapsed between the sixth and seventh editions of my book, my doctrine was as good as buried, by the majority of practical agriculturists it was held to be completely refuted, which might well be quite unhesitatingly assumed since one of the most renowned Scientific Societies had bestowed its great gold medal upon my most persevering opponents, as a seal of their triumph over the mineral theory. With the publication of the seventh edition of my 'Chemistry in its applications to Agriculture and Physiology,' a refutation of my doctrine is no longer spoken of, and the younger generation of farmers, standing in a far higher scientific position, no longer comprehend how there was so

much disputing and quarrelling over truths which now seem to them self-evident.”*

Considering that the “Mineral Theory,” about which there was so much “disputing and quarrelling” has in reality been so long both refuted and buried, and that its author not only seeks to repudiate it, but to adopt without acknowledgment the views of his opponents put forward in correction of his own, it would be only waste of the reader’s time to repeat the process of refutation and burial in any detail here. But those who may be curious to examine into the history and the truth of the matter for themselves, we would refer to the third and fourth English editions of Baron Liebig’s book (1843 and 1847), or to the German editions *prior to the seventh*, and to our own papers in Volumes xii., xvi., xxiv., and xxv. of the ‘Journal of the Royal Agricultural Society of England.’

Before commencing the consideration of the individual seasons, it may be well to add, by way of preliminary statement, that in the comments on the varying quantity and quality of produce obtained by one and the same manure according to season, the comparisons of the produce of each separate season with the average of the twenty seasons, will be made with as little reference as may be needed to the question of how far the result may be affected by the use of the same manure year after year on the same plot. In accordance with the plan already given, this subject, of the degree, or the limit, of the effects of accumulation, or of exhaustion, by previous manuring and cropping, on the produce of succeeding seasons, will receive separate and full consideration in Section IV.

Lastly, it will be useful to bear in mind throughout, that, so far as the influence of *season* is concerned, the *quantity* of the produce depends greatly on the amount and the distribution of rain during the growing period; and the *quality* (proportion of corn and quality of corn), on a suitable adaptation of temperature. And, so far as the influence of *manures* is concerned, the

* The following is the paragraph from the original—

“In dieser Weise war es meinen Ansichten über den Feldbaubetrieb, über die Ursachen der Erschöpfung der Felder und die Bedingungen der Wiederherstellung ihrer Fruchtbarkeit ergangen; in den 16 Jahren, die zwischen der 6. und 7. Auflage meines Buches liegen, war meine Lehre so gut wie zu Grabe getragen, sie wurde von der grossen Mehrzahl der practischen Landwirthe für vollkommen widerlegt gehalten, was wohl ganz unzweifelhaft daraus entnommen werden dürfte, dass eine der berühmtesten wissenschaftlichen Gesellschaften ihre grosse goldene Medaille meinen beharrlichsten Gegnern zur Besiegelung ihres Triumphes über die Mineraltheorie verliehen hat. Mit der Veröffentlichung der 7. Auflage meiner ‘Chemie in ihrer Anwendung auf Agricultur und Physiologie,’ ist von einer Widerlegung meiner Lehre nicht mehr die Rede, und die jüngere, wissenschaftlich weit höher stehende Generation der Landwirthe begreift es nicht mehr, dass so viel Hader und Zank über Wahrheiten war, die ihnen jetzt als selbstverständlich gelten.” (Ueber Gährung, über Quelle der Muskelkraft und Ernährung. Vorrede, pp. ix-x.)

quantity (luxuriance) depends greatly on the available supply of nitrogen within the soil, and the *quality* of the crop (tendency to form seed and to ripen), on the available supply of mineral or ash-constituents.

First Season, 1852.

November and December, 1851, were upon the whole fine, but colder than usual. January and February, 1852, were mild and wet; March dry and clear, but cold and frosty; April dry, with some hot sun, but a good deal of cold east wind; May variable, but also with a good deal of cold east wind; June very wet and cold; July very hot, with several heavy thunderstorms; August fine at the beginning, very wet in the middle, and fine and hot at the end; September fine until the 6th, when there was a heavy thunderstorm, with a good deal of rain, the rest of the month being variable, with prevailing low temperatures, but upon the whole not unfavourable. In June the dew point was below, but the degree of humidity of the air slightly above the average; in July the dew point was above, but the degree of humidity considerably below the average; and in August and September both dew point and the degree of humidity were below the average.

Thus, the early portions of the winter were, upon the whole, fine but cold; but the later for the most part mild and wet. Then followed drier weather, allowing of an early working of the land. The spring was, however, dry, cold, and backward; the early summer rainy and cold, and the maturing period variable, with a good deal of hot weather, and some heavy storms.

The winter-sown wheat crop was reported to be generally not deficient in bulk, but in many districts much blighted, mildewed, and grown; the result being a yield considerably below the average. Shortly before harvest, barley as well as wheat was reported to be a bulky crop, and to give upon the whole a fair promise, though the hot weather of July was tending to premature ripening, especially on the lighter lands; and the very variable weather of the maturing period greatly lessened the yield, and injured the sample.

The experimental wheat crop was much below the average in quantity of both corn and straw, and also considerably below the average in quality of grain. Table II. (p. 18) exhibits the results obtained on the selected plots in the experimental barley field.

The weather was favourable for the preparation of the land, and the seed (Chevalier) was sown on March 5. The quantity of produce, both corn and straw, was, without manure, by mineral manure alone, and by ammonia-salts alone, considerably greater in this first season than on the average of the 20 years under the same continued conditions as to manure. The comparatively

TABLE II.—Quantity and Quality of Barley on Selected Plots. First Season, 1852.

Plots.	MANURES, PER ACRE.	PRODUCE PER ACRE, &c.					
		Dressed Corn.		Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn to 100 Straw.
		Quantity.	Weight per Bushel.				
		Bushels.	lbs.	lbs.	Cwt.	lbs.	
7	14 Tons Farmyard Manure	33	52·8	1844	18½	3920	88·8
1 O	Unmanured	27½	52·1	1585	16½	3445	85·2
4 O	Mixed Mineral Manure ..	32½	51·5	1819	19½	4008	83·1
1 A	200 lbs. Ammonia-salts ..	36½	50·7	2088	22½	4652	81·5
4 A	Mixed Mineral Manure, and 200 lbs. Ammonia-salts ..	40½	51·4	2368	27½	5487	75·9
4 A A	Mixed Mineral Manure, and 400 lbs. Ammonia-salts ..	45½	50·6	2532	28½	5714	79·6
4 C	Mixed Mineral Manure, and 2000 lbs. Rape-cake ..	38	51·4	2098	24½	4796	77·7

large produce without manure, and by mineral manure alone, in the first year, shows that there was a quantity of unexhausted nitrogen from previous manuring available within the soil. The larger produce by ammonia-salts alone in the first than over the 20 seasons shows, in like manner, a comparative exhaustion of available mineral constituents in the later years. On the other hand, in the case of the farmyard manure, and the artificial manures in which there was annually supplied an abundance of mineral constituents as well as ammonia, or nitrogen in some form, the average produce of the 20 years considerably exceeded that of the first year. Part of this latter result is doubtless due to accumulation from year to year; but no doubt it is also in great measure due to the comparatively defective productive characters of the first season. This conclusion is confirmed by the fact that, the quality of the produce, as indicated by the weight per bushel, was, both from the deficiently and from the liberally manured plots, considerably below the average. The proportion of corn to straw was also in most cases below the average.

The results obtained in the experimental field are accordant, therefore, with those over a considerable area of the country, in showing that the variable, but upon the whole wet and cold season of 1852, was unfavourable to the barley crop, and especially so in point of quality.

Second Season, 1853.

Up to the middle of January, the winter of 1852-3 was, upon the whole, very unseasonably warm and wet; the rest of January, February, and March, were very cold, with a good deal of east

and north-east wind, and some snow; April and May were for the most part cold and wet, with the exception of a short period in the middle of each month; June was variable, with a good deal of rain and cold wind; the greater part of July was excessively wet, with low temperatures, but the end of the month, and the beginning of August, were fine; the remainder of August, and September, were dull, unsettled, wet, and cold. Both the dew point and the degree of humidity of the air were generally, and, especially the latter, sometimes considerably below the average in June, July, August, and September.

Thus the autumn and early winter were exceedingly wet; so much so, indeed, that a considerable breadth of the land intended for wheat could not be sown. The remainder of the winter, and the spring, were for the most part unseasonably cold, or cold and wet; so also were the summer, and the harvest time, with the exception of a short period at the end of July and the beginning of August.

The wheat crop was reported to cover a very limited area, and to be far inferior to that of any season for many years past. Barley and oats were, however, sown over an unusually large area, and neither crop was reported to have suffered anything like so much as wheat.

The experimental wheat was not sown until the spring, and its crop was one of the worst that has been obtained up to the present time. The experimental barley was not sown until April 11; and the following are the results obtained on the selected plots:—

TABLE III.—Quantity and Quality of Barley on Selected Plots. Second Season, 1853.

Plots.	MANURES, PER ACRE.	PRODUCE PER ACRE, &c.					
		Dressed Corn.		Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn to 100 Straw.
		Quantity.	Weight per Bushel.				
		Bushels.	lbs.	lbs.	Cwts.	lbs.	
7	14 Tons Farmyard Manure	36½	51·6	2136	22½	4682	83·9
1 O	Unmanured	25½	51·4	1552	18	3562	77·2
4 O	Mixed Mineral Manure ..	35½	52·1	2017	20½	4312	87·9
1 A	200 lbs. Ammonia-salts ..	38½	52·4	2285	23½	4950	85·7
4 A	Mixed Mineral Manure, and 200 lbs. Ammonia-salts ..	38½	53·1	2309	26½	5284	77·6
4 A A	Mixed Mineral Manure, and 400 lbs. Ammonia-salts ..	44½	51·4	2590	31½	6134	73·1
4 C	Mixed Mineral Manure, and 2000 lbs. Rape-cake	40½	50·4	2302	27½	5386	74·6

Under the influence of this unusually cold and wet season, the weight of total produce (corn and straw together) was, without

manure, and with the partial manures, that is, with mixed mineral manure alone, or ammonia-salts alone, rather more than in the first season, and very considerably more than the average of the 20 seasons. With farmyard manure it was considerably more than in the first season, but considerably less than the average. With the more complete artificial manures, supplying mineral constituents in abundance as well as ammonia, there was a considerable deficiency compared with the average; and more in the corn than in the straw. This comparatively worse result in the cold and wet season with the more liberal, than with the more partial manuring, is in great measure to be explained by the fact, that all the heavier crops were very much more laid than the lighter ones. Accordingly, the weight per bushel of dressed corn, which was in almost every case considerably lower than the average, was, so far as the artificial manures were concerned, the lower the higher the proportion of nitrogen to the mineral constituents in the manure; that is to say, the more the tendency to luxuriance, or quantity of gross produce, prevailed over that of seed-forming and ripening.

The results as a whole are an illustration of that which common experience teaches, namely, that with a cold and wet season the naturally light and poor, and the poorly manured lands, suffer much less than the naturally better, or more liberally manured soils. Another point of general interest is, that spring-sown corn as a rule suffers much less in such a season than the winter-sown wheat. Indeed, an amount of spring and summer rain which may be essential for the luxuriant growth, and subsequent yield, of the late-sown barley or oat crop, will frequently be adverse to the yield of the winter-sown wheat crop.

Third Season, 1854.

The winter of 1853-4 was, until past the middle of February, upon the whole unusually severe, with a good deal of snow; March and the greater part of April were very fine, but at the end of the latter month there was severe frost for the period, and a good deal of cold north wind; May was variable, generally cold and backward, with a good deal of rain; June was generally fine, but cold; the first half of July was also cold, with a moderate amount of rain; then came a week or two of fine hot weather, which was succeeded by thunderstorms and heavy rain; the beginning of August was wet, the middle fine though not warm, but the end dry and hot; September was almost throughout fine and favourable for getting in the crops, with high day, though low night, temperatures. In June, July, August, and September, the dew point was below the average, and the degree of humidity

of the air was, in June above, in July about, and in August and September below, the average.

The autumn seed-time had been very favourable; it was followed by an unusually severe winter, but the spring seed-time was not unfavourable. This was succeeded by generally fine but generally cold and backward weather, until the middle of July, from which time, however, until harvest, the period, though changeable, embraced some fine maturing and harvest weather.

The season of 1854 appears, therefore, by the climatic records, to have been by no means continuously favourable, and the harvest was late; yet the wheat-crop of the country was reported to be one of the largest yield per acre for many years past. The barley and oat crops were also spoken of as generally very good.

The experimental wheat-crop was as remarkable for superiority in almost every particular, both of quantity and quality, as that of 1853 had been in the opposite direction. The following results were obtained in the experimental barley field:—

TABLE IV.—Quantity and Quality of Barley on Selected Plots. Third Season, 1854.

Plots.	MANURES, PER ACRE.	PRODUCE PER ACRE, &c.					
		Dressed Corn.		Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn to 100 Straw.
		Quantity.	Weight per Bushel.				
		Bushels.	lbs.	lbs.	Cwts.	lbs.	
7	14 Tons Farmyard Manure	56½	53·9	3127	37½	7298	75·0
1 O	Unmanured	35	53·6	1963	21½	4405	80·4
4 O	Mixed Mineral Manure ..	42	54·0	2374	23½	4969	91·5
1 A	200 lbs. Ammonia-salts ..	47½	53·6	2763	30½	6155	81·5
4 A	Mixed Mineral Manure, and 200 lbs. Ammonia-salts ..	60½	54·3	3428	40½	7958	75·7
4 A A	Mixed Mineral Manure, and 400 lbs. Ammonia-salts ..	62½	52·1	3539	49	9026	64·5
4 C	Mixed Mineral Manure, and 2000 lbs. Rape-cake ..	60½	52·8	3413	42½	8125	72·4

The seed was sown as early as February 24th; and the season, though backward, was without material checks. The result, with the early start, and these conditions, was a great bulk of produce, which, for its amount, was comparatively little laid; and, with favourable harvest weather, it finally yielded a large amount of corn as well as straw, and generally a good weight per bushel. Under every condition of manuring the produce was considerably higher than in either of the two preceding seasons, and considerably higher also than the average of the 20 seasons. It was, in fact, under most of the conditions of manuring, in straw higher, and in corn also higher than, or nearly as high as,

in any of the 20 years. In 3 of the selected cases the produce exceeded 60 bushels of dressed corn, and 2 tons of straw, per acre. The season of 1854 was, therefore, one of remarkable productiveness; and it was remarkable for yielding such large crops under climatal conditions which the mere meteorological registry did not indicate to be peculiarly favourable. The result would appear to have been owing, as in the also remarkable season of 1863, to a continuity of unchecked growth, rather than to any special aptitude for unusual luxuriance at particular periods. Lastly, although the quantity of grain per acre was very large, the proportion of corn to straw was considerably below the average. It is probable, indeed, that the great yield was due to favourable conditions of season at the time of seed-forming, acting upon a great bulk of plant, and not to conditions favourable to seeding tendency through any lengthened period of growth.

Fourth Season, 1855.

The winter of 1854-55 was generally fine and mild up to the middle of January. Then came some frosts and deep snow; and the frost, with occasional snow, rain, and thaw, lasted, with more or less severity, through February and March. The beginning and end of April were also cold and frosty, and the month was more or less windy throughout, with dry east winds at the close. May and June were for the most part very cold and dry, with the exception of a short interval in the middle of that period, and the end of June, which was very hot; July was very variable, with many fine hot days, but with severe thunderstorms, and, upon the whole, a great excess of rain. The beginning of August was also wet, but the remainder of the month was fine; September also was fine, but cool. In June, August, and September, both the dew point and the degree of humidity of the atmosphere ranged low, but in July both were somewhat in excess of the average.

Thus, the latter part of the winter, and the early spring, were extremely severe; the remainder of the spring and the early summer cold and dry; July was very variable, with a great deal of rain, and a rather humid atmosphere; but the harvest period was more favourable.

With these characters of season, the wheat crop of 1855 was reported to be much less abundant than that of 1854; in quantity about, or but little over, an average—in quality very various, and in many cases much damaged. Barley was reported to be abundant, but damaged, yielding a bad malting sample.

In the experimental wheat field, the season of 1855 was one of

average productiveness with moderate manuring, but was unfavourable for high manuring, that is for the growth and maturing of large crops. The selected plots in the experimental barley field gave the following results:—

TABLE V.—Quantity and Quality of Barley on Selected Plots. Fourth Season, 1855.

Plots.	MANURES, PER ACRE.	PRODUCE PER ACRE, &c.					
		Dressed Corn.		Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn to 100 Straw.
		Quantity.	Weight per Bushel.				
		Bushels.	lbs.	lbs.	Cwts.	lbs.	
7	14 Tons Farmyard Manure	50½	52·9	2765	27½	5852	89·6
1 O	Unmanured	31	52·4	1773	17½	3745	89·9
4 O	Mixed Mineral Manure ..	37½	53·1	2067	18	4082	102·6
1 A	200 lbs. Ammonia-salts ..	44½	51·8	2443	24½	5148	90·3
4 A	Mixed Mineral Manure, and 200 lbs. Ammonia-salts ..	48½	52·0	2659	31	6134	76·5
4 A A	Mixed Mineral Manure, and 400 lbs. Ammonia-salts ..	49½	48·9	2582	39½	7054	57·7
4 C	Mixed Mineral Manure, and 2000 lbs. Rape-cake ..	51½	49·5	2783	37½	6993	66·1

A wet and warm July, and the beginning of August also wet, following upon a cold and dry spring and early summer, and, therefore, acting upon a backward crop, ensured a considerable bulk of produce; and with comparatively favourable conditions immediately before harvest, the quantity of corn per acre, as well as that of straw, was also above the average of the 20 years; excepting in some of the cases of the heavier crops, which were much laid. The corn-yielding characters of the crop varied, however, very considerably; the proportion of corn to straw, and the weight per bushel of the dressed corn, being generally considerably the lower, the greater the proportion of nitrogen to mineral constituents in the manure; that is to say, the more the manures supplied the conditions favourable to luxuriance and bulk, rather than to seeding tendency. Thus, by mineral manures alone, there are only 37½ bushels of corn, and 18 cwts. of straw, but 102 parts of corn for 100 of straw, and more than 53 lbs. weight per bushel; whilst with the same mineral manure and 400 lbs. ammonia-salts per acre, there are nearly 50 bushels of corn, and nearly 40 cwts. of straw, but less than 58 parts of corn to 100 of straw, and less than 49 lbs. per bushel. The very varied conditions of manuring supplied in the experimental field have, therefore, furnished, in their results, a striking illustration of how differently the same conditions of season may affect the produce of light and of heavy, or of deficiently or highly manured land; and how an excess of rain during the actively growing

period may be beneficial under bad, and injurious under good agricultural conditions.

Fifth Season, 1856.

After a wet autumn, and some severe weather in the early part of the winter, January 1856 was very variable, but, upon the whole, mild, as was also February; March was dry and cold, with piercing north-east winds; April and May generally cold, and May particularly, very wet; June and July changeable as to temperature, with little rain, and frequently very cold nights until nearly the end of the latter month, which, with the beginning of August, was fine and hot; then came heavy thunderstorms with excessive rain, but the end of August, and the first half of September, were fine, after which again succeeded thunderstorms and heavy rain, the temperature being generally low throughout the month. The mean dew point, and degree of humidity of the air, were above, or about, the average in June, July, and August, and somewhat below it in September.

Thus, after a variable, but upon the whole, mild winter, the early spring was dry and cold, the remainder cold and wet, and the early summer cold and changeable, with little rain; then came a short interval of fine and hot weather, succeeded about the ripening period by very heavy rains and prevailing low temperatures. The harvest period was much broken, generally wet and unfavourable, especially in the later districts.

Wheat was reported to cover a large area; and shortly before harvest it was thought the crop would be over an average. Barley and oats were also expected to be over average per acre; though barley was said to cover an unusually small area. Eventually, however, owing to the unfavourable harvest-weather, and the deficiency of labour, a considerable proportion of all three crops was much damaged and badly got in.

The experimental wheat crop was, with liberal manuring, in quantity of straw over, and in that of grain fully equal to, the average; but it was unevenly and badly ripened, and the weight per bushel was low.

The results exhibited in Table VI. (p. 25) were obtained in the experimental barley field.

The barley was sown on March 8th; and with, for the most part, alternately cold and dry, and cold and wet, spring and summer, the amount of total produce was, under all conditions of manuring, very considerably below the average of the 20 years. The deficiency in quantity of corn was very great, and that of straw also great; though the less the higher the artificial manuring. With the farmyard manure, however, the deficiency

TABLE VI.—Quantity and Quality of Barley on Selected Plots. Fifth Season, 1856.

Plots.	MANURES, PER ACRE.	PRODUCE PER ACRE, &c.					
		Dressed Corn.		Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn to 100 Straw.
		Quantity.	Weight per Bushel.				
		Bushels.	lbs.	lbs.	Cwts.	lbs.	
7	14 Tons Farmyard Manure	32½	47·1	1656	19½	3866	74·9
1 O	Unmanured	13½	49·1	812	8½	1797	82·4
4 O	Mixed Mineral Manure ..	19½	47·0	1018	9½	2075	96·3
1 A	200 lbs. Ammonia-salts ..	25	48·5	1432	17½	3347	74·8
4 A	Mixed Mineral Manure, and 200 lbs. Ammonia-salts ..	31½	46·4	1599	21½	3981	67·1
4 A A	Mixed Mineral Manure, and 400 lbs. Ammonia-salts ..	37½	45·4	1886	33	5582	51·0
4 C	Mixed Mineral Manure, and 2000 lbs. Rape-cake ..	35½	46·3	1841	30½	5257	53·9

of straw was proportionally as great as in other cases of low produce. The quantity of corn was, indeed, under many of the conditions of manuring, the lowest, and under all nearly as low, as in any year of the 20; and, with a wet harvest time following upon an almost continuously unfavourable growing period, the proportion of corn to straw was unusually low, especially under the high manuring. The weight per bushel of dressed corn was also very much below the average, and almost throughout lower than in any other of the 20 seasons.

In former seasons it had been observed that, wherever phosphatic manures were used, the crop ripened much earlier than where they were not employed; but hitherto it had been thought desirable to cut all at the same time. From this time forward, however, there have generally been at least two cuttings, with an interval of from a week to a fortnight between them. In the case of the season under consideration, all the lots with phosphatic manure were cut on August 13th, after which there was a week of almost incessant rain, which much damaged both grain and straw, the former being much sprouted. The remainder of the plots were cut on August 29th, and being then dead ripe, were carted on the same day.

Judging from the reports, it would appear that the barley crop of the country generally was not so deficient in bulk as the results show that in the experimental field to have been; but it was probably in many cases equally damaged, and bad in yield.

Sixth Season, 1857.

The last quarter of 1856 was marked by rapid variations of pressure, and extreme changes of temperature. In January

(1857), there was a good deal of rain, and the greater part of the month was mild; but it became colder, with frost and snow, at the end of the month and the beginning of February. The remainder of February, and March, were very dry, with high barometer, frequent sharp frosty nights, and cold easterly winds. April was more rainy, but included also some fine though cold weather. May was fine, with a good deal of very warm weather, and but little rain. In June, again, there was a good deal of fine and hot weather; but there were also several thunderstorms, with heavy falls of rain, which were much needed, and thoroughly penetrated the soil. During July the weather was generally fine, and occasionally very hot, with much less than the usual amount of rain. In August there were several thunderstorms with heavy rain, but otherwise the weather was fine and remarkably hot. In the early part of September a great deal of rain fell, but the remainder of the month was fine, and its temperature was pretty uniformly rather above the average. In June, July, and August, though the dew point ranged somewhat high, the temperature did so in a greater degree, so that the atmosphere was drier than usual.

Thus, after a variable preliminary period, the beginning of the year was mild and wet; in the spring there was, upon the whole, a good deal of cold dry weather, but there was a sufficiency of rain in April. The summer was for the most part hot, with a dry atmosphere, but with genial and plentiful rains in June, and again in the beginning of August. Finally, the harvest period, though somewhat broken, was generally favourable.

The extent of land under wheat was reported to be less than in 1856; but with a summer hotter and drier than usual, though with occasional plentiful rains when most needed, the crop throughout promised exceedingly well; and, after harvest, it was estimated to have been unusually productive. Barley was said to cover a large area, but to be generally deficient in yield per acre, though proportionally less so in the best corn-growing districts of the country. Oats were pronounced to be decidedly below their average productiveness.

The experimental wheat crop, though by no means so bulky as many, was one of very much more than the average yield of grain per acre.

The results obtained with barley are shown in Table VII. (p. 27).

The seed was sown on March 6th. On all the plots having superphosphate in the manure, the crops were ripe earlier than on the others, and were cut on August 3rd, the rest being left till August 10th. In April there was a sufficiency of rain to

TABLE VII.—Quantity and Quality of Barley on Selected Plots. Sixth Season, 1857.

Plots.	MANURES, PER ACRE.	PRODUCE PER ACRE, &c.					
		Dressed Corn.		Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn to 100 Straw.
		Quantity.	Weight per Bushel.				
		Bushels.	lbs.	lbs.	Cwts.	lbs.	
7	14 Tons Farmyard Manure	51½	54·2	2915	23½	5564	110·0
1 O	Unmanured	26½	52·0	1453	12½	2878	102·0
4 O	Mixed Mineral Manure ..	39½	53·7	2191	17½	4111	114·1
1 A	200 lbs. Ammonia-salts ..	38½	51·9	2133	17½	4118	107·5
4 A	Mixed Mineral Manure, and 200 lbs. Ammonia-salts ..	57½	54·8	3216	27½	6386	103·1
4 A A	Mixed Mineral Manure, and 400 lbs. Ammonia-salts ..	64½	53·9	3677	36½	7734	90·6
4 C	Mixed Mineral Manure, and 2000 lbs. Rape-cake ..	62½	54·1	3536	33½	7241	95·4

establish growth; the summer was almost throughout hot and dry, excepting that there were some heavy falls of rain in June, and again in August; and the result was a crop of more than average bulk, and of very unusual seeding tendency. In fact, there was a higher proportion of corn to straw, and higher weight per bushel of corn, than in any other year of equal gross produce per acre. The season was remarkably favourable for high manuring; and even the heaviest crops, which were very heavy, especially in the ear, were very little laid. Thus, there were, with mineral manure and 400 lbs. of ammonia-salts per acre, 90½ parts of corn for 100 of straw, nearly 65 bushels of dressed corn per acre, and 53·9 lbs. weight per bushel. Again, with mineral manure and 2000 lbs. rape-cake, there were 95½ corn to 100 of straw, 62½ bushels of dressed corn per acre, and a weight per bushel of 54·1 lbs.

The contrast between this season and its produce, and those of 1854, which was also a year of very unusual productiveness, is very great. Throughout the most active growing periods the temperature was very much lower in 1854 than in 1857. In May, 1854, there was about four times as much rain as in May, 1857; but in June and July there was less than half as much, though nearly as many rainy days. The consequence was very much more gross produce per acre, in 1854; and, with the highest manuring, about one-fourth more straw, but scarcely as much corn, as in 1857.

It would appear that the season of 1857 was much more strikingly favourable for the barley crop in the experimental field than, according to the published reports, it was estimated to be in the country generally. Thus, the crop was stated to be,

upon the whole, of barely average yield per acre ; though it was admitted to be good in the best corn-growing districts.

Seventh Season, 1858.

The last quarter of 1857 was generally mild, with unusually little rain during the last two months. January, 1858, was also dry, and, during the last fortnight, cold and frosty. February was cold, moderately rainy, with some snow, sharp frosts, and easterly winds, which extended some time into March ; in which month there was comparatively little rain. The beginning of April was cold, but most of the remainder fine, and even hot ; and a moderate amount of rain fell in the beginning and end of the month. It was also cold in the beginning of May, but fine, dry, and hot towards the end ; though with heavy showers, making up about an average fall of rain during the month. June was upon the whole very fine, dry, and hot, with some heavy thunder-showers, but much less than the average amount of rain. In July there was much more rain ; and, though variable, the weather was still upon the whole fine and hot. August and September were very fine, with much less than the average fall of rain. Throughout the quarter ending with September, as also in June, the degree of humidity of the atmosphere ranged lower than usual.

There was, therefore, during the winter, spring, and summer, upon the whole, much less than the usual amount of rain ; though in February, April, May, and July, there were fair amounts. The air was also generally less humid than usual throughout the summer. The temperature, too, was generally above the average throughout the spring and summer months, whilst June was unusually hot.

Early in the summer the appearance of the wheat plant was generally that of great luxuriance, promising a bulky crop. The reports of the harvest indicated a crop, fully, if not above, the average, though by no means equal to the extraordinary one of 1857. Barley and oats were said to be very various, neither likely to give an average as to quantity ; and barley not very good in quality.

The experimental wheat crop was pretty uniformly below the average in quantity of straw, but the produce of grain was generally above the average, and the more so the higher the manuring.

The results obtained with barley are shown in Table VIII. (p. 29).

Hitherto we have been able to show the effects of mixed mineral manure alone, the same with 200 lbs. ammonia-salts, the same with

TABLE VIII.—Quantity and Quality of Barley on Selected Plots.
Seventh Season, 1858.

Plots.	MANURES, PER ACRE.	PRODUCE PER ACRE, &c.					
		Dressed Corn.		Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn to 100 Straw.
		Quantity.	Weight per Bush.				
7	14 Tons Farmyard Manure	55	54.5	3118	31½	6635	88.7
1 O	Unmanured	21½	53.0	1207	10½	2424	99.1
4 O	Mixed Mineral Manure ..	30½	54.0	1780	16½	3590	98.3
1 A	200 lbs. Ammonia-salts ..	31½	53.0	1771	15½	3506	102.1
4 A	Mixed Mineral Manure, and } 200 lbs. Ammonia-salts ..	51½	54.0	2897	29½	6192	87.9
4 A A	Mixed Mineral Manure, and } 200 lbs. (¹) Ammonia-salts	56½	53.5	3155	35½	7160	78.8
4 C	Mixed Mineral Manure, and } 1000 lbs. (²) Rape-cake ..	57½	53.1	3162	35	7082	80.7

(¹) 400 lbs. the first 6 years (1852-7).

(²) 2000 lbs. the first 6 years (1852-7).

400 lbs. ammonia-salts, and the same with 2000 lbs. of rape-cake per acre. The crops manured with 400 lbs. ammonia-salts, and 2000 lbs. of rape-cake, were, however, always obviously too heavy to stand up and ripen well in other than most exceptional seasons. For the crop of 1858, therefore, and subsequently, the quantity of rape-cake was reduced from 2000 to 1000 lbs. per acre. The quantity of ammonia-salts applied to the "A A" plots was, at the same time, reduced from 400 to 200 lbs. per acre; and this dressing was continued for ten years, namely, to 1867 inclusive, after which the 200 lbs. of ammonia-salts was substituted by 275 lbs. of nitrate of soda, which is estimated to contain the same quantity of nitrogen. From this time, therefore—1858 and afterwards—any increase of produce on plot 4 A A, over that on plot 4 A, (with only 200 lbs. of ammonia-salts per acre from the commencement), is, doubtless, in great measure, due to an unexhausted residue of nitrogen supplied in the 400 lbs. of ammonia-salts used annually during the preceding six years; and it will afterwards be seen that there was a marked effect from the previous excessive manuring, at any rate over ten consecutive seasons. In like manner, the produce on the plot manured with mineral manure and 1000 lbs. rape-cake in this and subsequent seasons, will be affected by the unexhausted residue from the excessive supply in the first six years.

The seed was sown on March 20; the earlier plots were cut on August 4, and the later ones on August 17. Thus, with a rather limited, but still a sufficient, supply of rain for the requirements of growth, and a comparatively hot summer and harvest period, the crops ripened somewhat early. There was, under

most of the conditions of manuring, rather more than the average quantity of straw, more than the average proportion of corn to straw, especially with the most liberal manuring, notably more than the average quantity of corn per acre, and generally good, and full average, weight per bushel. Thus, under varied conditions of manuring, the season of 1858 was, in most particulars, one of more than average productiveness; but, in quantity of total produce, in proportion of corn to straw, and especially in quantity of corn per acre, it was considerably below that of the much hotter and pre-eminently *corn*-yielding season of 1857.

The experimental wheat-crop accorded pretty well in characters with that of the country generally; and the experimental barley-crop has much the characters of the experimental wheat-crop, namely, greater superiority in yield of corn than in produce of straw, when compared with the average; but the barley-crop of the country at large was, according to the reports, by no means so good as that in the experimental field is seen to have been.

Eighth Season, 1859.

The concluding quarter of 1858 was much drier than usual, and, during a considerable portion of it, it was very cold. The latter part of December, however, and January and February, 1859, were very fine and mild; March was also, upon the whole, mild, but with more rain; in April, too, a good deal of rain fell, and the latter part of the month was stormy, wet, and cold. May began with cold, dry, easterly winds; then came a good deal of rain, succeeded by fine and hot weather. During June there were several heavy thunderstorms, much rain fell, and the air was more humid than usual, though there was also some fine warm weather. July was, upon the whole, fine, and unusually hot; but there were several severe thunderstorms at the beginning and about the middle of the month. August was unsettled, but, for the most part, warm, with a good deal of rain. September was also unsettled, and cold, with an excessive amount of rain. In July the dew-point ranged high, but the temperature relatively higher; and, throughout the quarter ending with September, the degree of humidity of the air was below the average.

Thus, throughout the winter there was very little rain; and, with the exception of the early part, the weather was very mild. March was mild, with more rain; in April there was a full, in May a deficient, in June an excessive, in July a moderate, in August a full, and in September an excessive, supply of rain; whilst June and July were considerably above the average temperature, and the harvest period was generally unsettled, with a great deal of rain, and for the most part warm.

Early in the season the reports of the crops were, upon the whole, good; but the heavy rains of June laid the best of them, and the high temperature of that month, but especially of July, induced premature ripening; whilst, owing to the wet and stormy harvest period, and a deficiency of labour, much of them were too long out, and, especially the heavy ones, much damaged. Wheat was eventually pronounced to be under average, much injured, and very poor in quality: barley, a very uneven crop, with very thin grain, and a good deal sprouted; oats also very deficient.

The experimental wheat was unusually bulky with high manuring. With only moderate amounts of ammonia the quantity even of grain was not deficient; but, with heavy dressings of ammonia there was, compared with the average, a considerable deficiency of corn, and a large amount, and very undue proportion, of straw. The weight per bushel of dressed corn was also throughout very low. The following are the results obtained with barley:—

TABLE IX.—Quantity and Quality of Barley on Selected Plots.
Eighth Season, 1859.

Plots.	MANURES, PER ACRE.	PRODUCE PER ACRE, &c.					
		Dressed Corn.		Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn to 100 Straw.
		Quantity.	Weight per Bush.				
		Bushels.	lbs.	lbs.	Cwts.	lbs.	
7	14 Tons Farmyard Manure	40	52·5	2362	28½	5558	73·9
1 O	Unmanured	13½	49·0	775	9½	1800	75·6
4 O	Mixed Mineral Manure ..	19½	52·5	1197	12½	2567	87·4
1 A	200 lbs. Ammonia-salts ..	15½	47·5	919	11½	2204	71·5
4 A	Mixed Mineral Manure, and 200 lbs. Ammonia-salts ..	34½	51·0	2017	27½	5067	66·1
4 A A	Mixed Mineral Manure, and 200 lbs. (¹) Ammonia-salts	35½	50·5	2092	30½	5517	61·1
4 C	Mixed Mineral Manure, and 1000 lbs. (²) Rape-cake ..	35	51·0	2135	29½	5440	64·6

(¹) 400 lbs. the first 6 years (1852-7).

(²) 2000 lbs. the first 6 years (1852-7).

The seed was sown on March 3; and with, upon the whole, mild weather, and a good deal of rain, for a couple of months, succeeded by heavy thunderstorms, but a considerable amount of hot weather, the crop came forward very early, the plots manured with superphosphate being cut on July 13, and carted on August 1; whilst the remainder were not cut until August 8, and were carted on August 12. With the wet spring, and premature ripening summer, there was a considerable deficiency of total produce, which showed itself proportionally much less in the straw where the manure was liberal than where it was de-

fective. The deficiency in quantity of corn was throughout very great, and the weight per bushel was also throughout low, and very low where superphosphate was not employed. The deficiency was the greatest in both corn and straw, and particularly in corn, where the ammonia-salts were used alone; that is to say, where there was the greatest excess of ammonia relatively to the supply of mineral constituents. The quantity of corn under that manuring was less than half, and that of the straw less than two-thirds, the average; and both corn and straw were absolutely less than in any either preceding or succeeding season, though this was only the eighth year of the twenty in which no mineral manure had been applied on that plot. Next to the plot manured with ammonia-salts alone, that continuously without manure was proportionally the worst in this season, compared with the average.

Thus, the general characters of the experimental barley crop, agree with those of the experimental wheat, in showing considerable deficiency; greater deficiency in corn than in straw, and greater where the manurial conditions were the most defective. The spring-sown barley suffered, however, more than the autumn-sown wheat; being not only more deficient in corn, but generally deficient in straw also, which the wheat crop was not. The comparatively greater deficiency of total produce of the barley, is probably due to the wet and warm weather, almost from the time of sowing. Sowing early would induce too much upward, and too little underground growth, thus leaving the plant without proper soil-resources in its later stages. The character of the experimental barley accords with that of the country generally, which, as has been seen, was stated to be uneven, prematurely ripened, and to yield thin grain, often sprouted.

Ninth Season, 1860.

The last quarter of 1859 was very variable as to temperature, but prevalingly cold; and upon the whole wet. January, 1860, was variable, but generally mild and wet; February was very cold, with sharp frosts and snow, ending with storms of rain and wind. The greater part of March was cold, with heavy showers, and snow; the remainder was finer and warmer. April was very cold, with some snow and sharp frosts; the beginning of May was also cold, but the rest of the month warmer than usual, though very wet. June was very cold and very wet; July also very cold, with a moderate amount of rain, most of which fell after the middle of the month; August cold and very wet, and September also cold, but fine in the early part, though very wet in the latter. In June, July, August, and September, the dew-

point generally ranged low; but with the unusually low temperatures, the degree of humidity of the air was considerably above the average.

Thus, the winter was alternately very mild and very cold, and upon the whole very wet. The spring, summer, and autumn, were very stormy, cold, wet, and unseasonable; indeed, more so than had been known for many years past.

The crops were very backward, and the harvest 2, 3, or more, weeks later than usual. Wheat was, in some localities, not deficient in bulk, but generally very much damaged, yielding but a small proportion of grain, and that of very low quality. The crop was, indeed, very much below the average, both in quantity and quality. Barley and oats were reported to be bulky, and generally abundant; but barley especially in many districts much laid and damaged, and giving grain of inferior quality.

Under the influence of the extraordinarily wet and cold growing and ripening season, the wheat-crop in the experimental field was very much below the average both in quantity and quality, though the deficiency was proportionally less with the heavier dressings. The crop was generally worse than any other, excepting that of 1853. The following results were obtained in the experimental barley field:—

TABLE X.—Quantity and Quality of Barley on Selected Plots. . Ninth Season, 1860.

Plots.	MANURES, PER ACRE.	PRODUCE PER ACRE, &c.					
		Dressed Corn.		Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn to 100 Straw.
		Quantity.	Weight per Bush.				
		Bushels.	lbs.	lbs.	Cwts.	lbs.	
7	14 Tons Farmyard Manure	41½	52·1	2319	25½	5156	81·7
1 O	Unmanured	13½	50·8	753	7½	1598	89·1
4 O	Mixed Mineral Manure ..	18½	51·3	1013	9½	2093	93·8
1 A	200 lbs. Ammonia-salts ..	26½	50·8	1501	14½	3166	90·2
4 A	Mixed Mineral Manure, and 200 lbs. Ammonia-salts ..	43½	51·1	2375	26½	5355	79·7
4 A A	Mixed Mineral Manure, and 200 lbs. (¹) Ammonia-salts	46½	51·0	2501	29	5746	77·1
4 C	Mixed Mineral Manure, and 1000 lbs. (²) Rape-cake ..	40½	51·1	2238	22½	4783	87·9

(¹) 400 lbs. the first 6 years (1852-7).

(²) 2000 lbs. the first 6 years (1852-7).

Bad as were the seasons of both 1859 and 1860, yet they show some remarkable contrasts. 1859 was wet, much rain falling in heavy storms, unusually warm, and very early, some of the plots in the experimental barley field being cut on July 13th. On the

other hand, 1860 was wet, the rain a good deal distributed, unusually cold and sunless, all crops were very late, and the experimental barley, which was sown on March 19th, was not cut until September 3rd and 4th. In the wet, warm, and early season of 1859, there was a very great deficiency of corn, low weight per bushel, and comparatively little deficiency of straw, especially where the manuring was liberal. In the wet, cold, and late season of 1860, there was much less deficiency of corn, especially with liberal nitrogenous manuring, about as low a weight per bushel as in 1859, and a somewhat greater, but still not great, deficiency of straw. The wet, cold, and late season, gave, therefore, upon the whole, a much better crop, and especially much more corn, with liberal nitrogenous manuring, than the wet, warm, and prematurely early season.

This result is very instructive, when it is borne in mind that it is with high temperature, provided there be a sufficiency and not an excess of rain, that nitrogenous manures the most strikingly increase the produce of grain. We have here an illustration of the dependence of the result on the mutual adaptations of heat, moisture, and stage of growth of the plant, and of how difficult it is, without going into considerable detail as to each of these three elements, and their relations to one another, thoroughly to anticipate, or to explain, the influence of any particular season. It will be remembered that the very remarkable productiveness of 1854, was by no means clearly indicated in the general characters of the season, as represented in the summary statement of the meteorological registry for the period. Doubtless, an influential element of the restricted productiveness in 1859, with the higher temperatures, was the fact of their distribution being such as to bring the plant much too early to maturity, thus shortening its period of accumulation and growth. On the other hand, the much better result with the wet and cold season of 1860, was probably greatly due to the less active above-ground, and probably greater under-ground development, early in the season, and to a much more extended subsequent period of growth.

It is worthy of remark that, whilst, with mineral manures and ammonia-salts or nitrate of soda, the experimental barley crop was so much better in yield of grain in 1860 than in 1859, the experimental wheat-crop was, with similar manures, much the most deficient, both in corn and straw, in 1860. The winter-sown wheat having acquired much more complete possession of the soil than the spring-sown barley, the high temperature of the summer of 1859 would in a much less degree check its luxuriance and induce premature ripening—that is much less curtail its total growth—and hence, with liberal nitrogenous

manuring we have, in its case, though a deficiency of corn, an even more than average total produce in the hot, but upon the whole wet, season of 1859; whilst with the barley there is a considerable deficiency of total produce, and more deficiency of corn than of straw. In the wet sunless season of 1860, on the other hand, the wheat, which requires higher temperatures for its luxuriance than barley, shows a great deficiency of total produce, more especially in the straw; and the barley less deficiency of total produce, and very much less deficiency of corn than in 1859. Lastly, it is remarkable, that although under the influence of the rapidly active artificial manures, there was such unusual deficiency of barley grain in the hot and early season of 1859, yet in the same season, the much less rapidly active, but much more comprehensive, manuring of farmyard dung gave a much less marked deficiency.

The results in the experimental fields are in accordance with the records of the crops in the country at large, in showing 1860 to have been for wheat a more, but for barley a less, adverse season than 1859.

Tenth Season, 1861.

October, 1860, was upon the whole seasonable; November very cold, with a good deal of rain; December mild at the beginning, but otherwise, as also the greater part of January (1861), extremely severe. Many evergreens of long standing were killed during this period. The remainder of January and February were much milder, with comparatively little rain; though during the latter month, as also pretty continuously through March, April, and the beginning of May, there was a good deal of cold wind, with less than the average fall of rain. The remainder of May was dry and fine, and even hot. June commenced with cold wind and rain, followed by an interval of fine and hot weather, and then a good deal of rain to the end of the month. July was generally seasonable as to temperature, with less than the average fall of rain. There was some heavy rain at the beginning of August, but, upon the whole, the month was very dry, fine, and favourable; and the fine weather continued, but with rather lower temperatures, and much wind, till nearly the end of September, when a considerable quantity of rain fell. In June, both the dew point and degree of humidity of the air ranged high; but in July, August, and September, they were not far from the average.

Thus, after, upon the whole, a favourable autumn seed-time, the winter of 1860-61 was unusually severe, and the young wheat-plant suffered considerably. The spring of 1861 was for the most part dry, with a good deal of cold wind; but plen-

tiful rains, and some hot weather, in June, brought the growing crops rapidly forward; July, August, and the greater part of September, were, upon the whole, seasonable as to temperature and degree of humidity of the atmosphere, with less than the usual amount of rain.

The wheat crop was reported to be generally below the average in quantity per acre, owing chiefly to the loss of plant during the winter; but it was much improved by the favourable weather of the latter part of the summer, and the autumn; and a fair average, and, in many cases, good quality, compensated somewhat for deficiency of quantity. Spring corn crops were, however, stated to be generally good; both barley and oats, especially the latter, yielding very well.

The experimental wheat crop was considerably deficient in straw, and somewhat so in grain; but the quality of the latter was fully equal to the average. The crop was, however, in all respects superior to that of 1860; and generally in yield, but especially in quality of grain, superior to that of 1859 also.

The selected plots in the experimental barley-field gave the following results:—

TABLE XI.—Quantity and Quality of Barley on Selected Plots. Tenth Season, 1861.

Plots.	MANURES, PER ACRE.	PRODUCE PER ACRE, &c.					
		Dressed Corn.		Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn to 100 Straw.
		Quantity.	Weight per Bush.				
		Bushels.	lbs.	lbs.	Cwts.	lbs.	
7	14 Tons Farmyard Manure	54½	54·8	3169	31½	6715	89·4
1 O	Unmanured	16½	52·8	941	11	2166	76·8
4 O	Mixed Mineral Manure ..	29½	54·0	1648	15½	3366	95·9
1 A	200 lbs. Ammonia-salts ..	30½	51·5	1745	19½	3945	79·3
4 A	Mixed Mineral Manure, and 200 lbs. Ammonia-salts ..	54½	54·0	3059	30½	6472	89·6
4 A A	Mixed Mineral Manure, and 200 lbs. (¹) Ammonia-salts }	55½	53·5	3169	33½	6937	84·1
4 C	Mixed Mineral Manure, and 1000 lbs. (²) Rape-cake ..	53½	54·3	3111	31	6576	89·8

(¹) 400 lbs. the first 6 years (1852-7).

(²) 2000 lbs. the first 6 years (1852-7).

Without manure, there was less than the average amount of both corn and straw; but, with every description of manure, there was more than the average quantity of straw, and with every description (excepting by ammonia-salts alone) more than the average quantity of corn; and with liberal manuring, whether in the form of farmyard dung, rape-cake, or mixed mineral manure and ammonia-salts, considerably more. The weight per

bushel of dressed corn was also, in most cases, fully equal to the average.

Thus, although the winter-sown wheat had given less than an average yield, the spring-sown barley gave much more than an average. The wheat had suffered from the severity of the winter, which would doubtless be favourable, rather than otherwise, so far as the condition of the land for the barley was concerned. Both were subjected to the influence of a dry, cold, and backward spring, which would tend to root-development rather than early aboveground luxuriance. Plentiful rains following in June, and again at the beginning of August, with, upon the whole, seasonable temperatures throughout the greater part of June, July, and August, conditions favourable for both crops were supplied. Hence, notwithstanding a deficient plant, the wheat turned out better than was expected; and the barley being not too forward in its early stages, and, under the conditions of season, probably well rooted, gave, upon the whole, a much more than average crop, especially of grain. It should be added, that the riper crops, those with superphosphate of lime in the manure, were not cut until August 20th and 21st, and the remainder not until August 27th. The earlier crops were, for the most part, a little laid, but none seriously.

It will be seen that these results, obtained in the experimental fields, accord very well with those reported in regard to the crops of the country at large.

Eleventh Season, 1862.

October, 1861, was generally mild, fine, and dry; November inclement, with an excess of rain, and unusually low temperature. December was, upon the whole, warmer and drier than the average, but with a good deal of cold wind towards the end. January and February (1862) were, upon the whole, fine and dry, with a good deal of warmer, and but little of colder, weather than usual. The beginning of March was frosty, but the greater part unusually mild and wet. April was variable, with some unseasonably cold, but a good deal of warm, weather; and a full average amount of rain. May was extremely wet, and, in the early part especially, unusually warm. June, July, and August were, almost throughout, unsettled, with a good deal of wind and rain, and unusually low temperatures, the nights especially being frequently very cold; and although the atmosphere contained less than the average actual amount of moisture, the degree of humidity of the air was, with the low temperatures, not correspondingly low. September was also variable,

with a good deal of rain at the beginning and end of the month, but with fine and warm weather intermediately.

The winter of 1861-2 was, therefore, upon the whole, mild. The spring was variable as to temperature, upon the whole warmer than usual, and very wet. The summer was unsettled, stormy, cold, and wet.

The wheat crop of the country was almost universally reported to be under the average, in many cases root-fallen, and also much mildewed. Barley was stated to be about, or scarcely, an average; oats a fair average.

The experimental wheat crops were, where the manuring was not excessive, fully equal to the average in both quantity and quality of grain, but, upon the whole, barely average in amount of straw.

The following results were obtained in the experimental barley-field :—

TABLE XII.—Quantity and Quality of Barley on Selected Plots.
Eleventh Season, 1862.

Plots.	MANURES, PER ACRE.	PRODUCE PER ACRE, &c.					
		Dressed Corn.		Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Oms to 100 Straw.
		Quantity.	Weight per Bush.				
		Bushels.	lbs.	lbs.	Cwts.	lbs.	
7	14 Tons Farm-yard Manure	49½	54·8	2936	34½	6774	76·5
1 O	Unmanured	16½	50·3	899	9½	1987	82·6
4 O	Mixed Mineral Manure ..	25½	52·0	1428	13½	2941	94·4
1 A	200 lbs. Ammonia-salts ..	31½	49·4	1821	20½	4106	79·7
4 A	Mixed Mineral Manure, and 200 lbs. Ammonia-salts ..	47½	54·0	2725	31½	6273	76·6
4 A A	Mixed Mineral Manure, and 200 lbs. (¹) Ammonia-salts ..	48½	54·0	2824	33½	6529	76·1
4 C	Mixed Mineral Manure, and 1000 lbs. (²) Rape-cake ..	45½	54·0	2634	28½	5872	81·4

(¹) 400 lbs. the first 6 years (1852-7).

(²) 2000 lbs. the first 6 years (1852-7).

As has been stated, March was unusually wet; the seed was not sown until April 16th; the earlier plots (those with superphosphate) were not cut until August 22nd, and the remainder not until September 1st. Excepting without manure, and with mineral manure alone, the quantity of barley-grain per acre was either close upon, or over, the average of the 20 years; and the weight per bushel of dressed corn was also, in most cases, fully or over the average. The superiority was the most marked with farmyard manure; and with it there was the greatest excess of straw as well as corn. With rape-cake, on the other hand, there was a slight deficiency of both straw and corn, the crops being

more laid than any of the rest. With the more liberal artificial manures there was, however, fully or over the average quantity of both corn and straw. Upon the whole, therefore, notwithstanding the prevailing coldness and wetness of the summer, the experimental barley-crop was somewhat over average, in both quantity and quality, under liberal conditions of manuring. The barley-crop of the country generally was pronounced to have been much less injuriously affected than wheat, and to have been about, whilst the latter was seriously below, the average. The experimental wheat, however, as well as the experimental barley, turned out to be rather over the average.

Twelfth Season, 1863.

October, 1862, was unusually warm, but with a good deal of wind and rain. November was cold, with comparatively little rain. December, and January and February 1863, were unusually mild, with a fair amount of rain in December, a good deal in January, and but little in February. March was, upon the whole, mild, with but little rain, and wheat showed unusually forward growth. April was very dry and warm. In May there were some refreshing rains, though only a small total fall, but the temperature was occasionally extremely low, and pretty nearly throughout rather below the average, with frequent storms of wind. The temperature in June was also generally rather below the average, and there was a great deal of rain, which, though needed, and much aiding growth, was so heavy as to lay the most forward and bulky crops. In July there was much less rain than usual, with moderately high day but low night temperatures, and some sharp night frosts. August, with only moderate temperature, and about the usual amount of rain, was, upon the whole, favourable for ripening and for harvest. In September a good deal of rain fell, and the temperature ranged rather low. In June the condition of the atmosphere as to moisture was about the average for that month. In July, August, and September, both the actual amount and the degree of humidity were below the average.

Thus, the winter and early spring were generally very mild, with, upon the whole, less than the usual fall, but in January an excess of rain. The remainder of the spring included some warmer, but more colder weather than usual, and there was, upon the whole, a deficiency of rain. The early summer was also cool, with more, and some heavy rain. From that time to harvest, though the temperature was seldom high, it was (excepting some night-frosts in July) generally sufficient, the fall of rain was

with a good deal of rain at the beginning and end of the month, but with fine and warm weather intermediately.

The winter of 1861-2 was, therefore, upon the whole, mild. The spring was variable as to temperature, upon the whole warmer than usual, and very wet. The summer was unsettled, stormy, cold, and wet.

The wheat crop of the country was almost universally reported to be under the average, in many cases root-fallen, and also much mildewed. Barley was stated to be about, or scarcely, an average; oats a fair average.

The experimental wheat crops were, where the manuring was not excessive, fully equal to the average in both quantity and quality of grain, but, upon the whole, barely average in amount of straw.

The following results were obtained in the experimental barley-field :—

TABLE XII.—Quantity and Quality of Barley on Selected Plots.
Eleventh Season, 1862.

Plots.	MANURES, PER ACRE.	PRODUCE PER ACRE, &c.					
		Dressed Corn.		Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn to 100 Straw.
		Quantity	Weight per Bush.				
		Bushels.	lbs.	lbs.	Cwts.	lbs.	
7	14 Tons Farm-yard Manure	49½	54·8	2936	34½	6774	76·5
1 O	Unmanured	16½	50·3	899	9½	1987	82·6
4 O	Mixed Mineral Manure ..	25½	52·0	1428	13½	2941	94·4
1 A	200 lbs. Ammonia-salts ..	31½	49·4	1821	20½	4106	79·7
4 A	Mixed Mineral Manure, and 200 lbs. Ammonia-salts ..	47½	54·0	2725	31½	6273	76·8
4 A A	Mixed Mineral Manure, and 200 lbs. (¹) Ammonia-salts ..	48½	54·0	2824	33½	6529	76·2
4 C	Mixed Mineral Manure, and 1000 lbs. (²) Rape-cake ..	45½	54·0	2634	28½	5872	81·4

(¹) 400 lbs. the first 6 years (1852-7).

(²) 2000 lbs. the first 6 years (1852-7).

As has been stated, March was unusually wet; the seed was not sown until April 16th; the earlier plots (those with super-phosphate) were not cut until August 22nd, and the remainder not until September 1st. Excepting without manure, and with mineral manure alone, the quantity of barley-grain per acre was either close upon, or over, the average of the 20 years; and the weight per bushel of dressed corn was also, in most cases, fully or over the average. The superiority was the most marked with farmyard manure; and with it there was the greatest excess of straw as well as corn. With rape-cake, on the other hand, there was a slight deficiency of both straw and corn, the crops being

more laid than any of the rest. With the more liberal artificial manures there was, however, fully or over the average quantity of both corn and straw. Upon the whole, therefore, notwithstanding the prevailing coldness and wetness of the summer, the experimental barley-crop was somewhat over average, in both quantity and quality, under liberal conditions of manuring. The barley-crop of the country generally was pronounced to have been much less injuriously affected than wheat, and to have been about, whilst the latter was seriously below, the average. The experimental wheat, however, as well as the experimental barley, turned out to be rather over the average.

Twelfth Season, 1863.

October, 1862, was unusually warm, but with a good deal of wind and rain. November was cold, with comparatively little rain. December, and January and February 1863, were unusually mild, with a fair amount of rain in December, a good deal in January, and but little in February. March was, upon the whole, mild, with but little rain, and wheat showed unusually forward growth. April was very dry and warm. In May there were some refreshing rains, though only a small total fall, but the temperature was occasionally extremely low, and pretty nearly throughout rather below the average, with frequent storms of wind. The temperature in June was also generally rather below the average, and there was a great deal of rain, which, though needed, and much aiding growth, was so heavy as to lay the most forward and bulky crops. In July there was much less rain than usual, with moderately high day but low night temperatures, and some sharp night frosts. August, with only moderate temperature, and about the usual amount of rain, was, upon the whole, favourable for ripening and for harvest. In September a good deal of rain fell, and the temperature ranged rather low. In June the condition of the atmosphere as to moisture was about the average for that month. In July, August, and September, both the actual amount and the degree of humidity were below the average.

Thus, the winter and early spring were generally very mild, with, upon the whole, less than the usual fall, but in January an excess of rain. The remainder of the spring included some warmer, but more colder weather than usual, and there was, upon the whole, a deficiency of rain. The early summer was also cool, with more, and some heavy rain. From that time to harvest, though the temperature was seldom high, it was (excepting some night-frosts in July) generally sufficient, the fall of rain was

considerably below the average, and the atmosphere comparatively dry.

With these characters of season, the wheat crop of 1863 was almost unanimously reported to be considerably above the average, both in quantity and quality. Indeed, such a yield per acre had not been known for very many years. The plant came very early forward, had refreshing though limited rains in its early stages, received comparatively few checks, and with a somewhat cool but sufficiently warm summer, with little rain and a comparatively dry atmosphere during the latter stages of growth, and the ripening and harvest periods, there was a lengthened and almost unbroken course of gradual accumulation. Spring-sown crops, especially barley, were reported to be less uniformly good—those that were late sown having suffered for want of rain in the early stages of growth. Still, both barley and oats were considered to be rather over the average.

The experimental wheat crop of 1863 was the twentieth in succession on the same land, yet it proved to be in quantity of both grain and straw by far the most productive, and in quality of grain nearly the best, hitherto. It even considerably exceeded both 1854 and 1857, which also were years of extraordinary yield. It was a very favourable season for the action of ammonia-salts, giving more total produce, and especially more corn, for a given amount of ammonia applied, than was obtained in any other year. The following are the results obtained on the selected plots in the experimental barley field:—

TABLE XIII.—Quantity and Quality of Barley on Selected Plots. Twelfth Season, 1863.

Plots.	MANURES, PER ACRE	PRODUCE PER ACRE, &c.					
		Dressed Corn.		Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn to 100 Straw.
		Quantity.	Weight per Bush.				
7	14 Tons Farmyard Manure	Bushels.	lbs.	lbs.	Cwts.	lbs.	
1 O	Unmanured	59½	57·2	3473	33½	7185	93·6
4 O	Mixed Mineral Manure ..	22½	53·6	1276	11½	2545	100·5
1 A	200 lbs. Ammonia-salts ..	33	54·8	1868	15½	3596	108·1
4 A	Mixed Mineral Manure, and 200 lbs. Ammonia-salts ..	42½	53·6	2406	21½	4806	100·3
4 A A	Mixed Mineral Manure, and 200 lbs. Ammonia-salts ..	55½	56·5	3210	32	6791	89·6
4 A A	Mixed Mineral Manure, and 200 lbs. (¹) Ammonia-salts ..	59½	56·4	3429	34½	7323	88·1
4 C	Mixed Mineral Manure, and 1000 lbs. (²) Rape-cake ..	54½	56·7	3159	30½	6599	91·8

(¹) 400 lbs. the first 6 years (1852-7).

(²) 2000 lbs. the first 6 years (1852-7).

The barley was sown on March 11; the forwardest plots were cut on August 10 and carted on August 14, and the remainder

cut on August 15 and carted on August 24. The seed was in, therefore, though not early, still in good time; and, with a mild but comparatively dry spring, the plant would probably distribute its feeders well through the soil, and with liberal rain in June, but no unduly forcing weather at any time, and favourable ripening and harvest periods, the result was, though not as with wheat in all respects the best crop hitherto, still one much over the average. It was so, especially in quantity and proportion of grain, whilst in quality, indicated by weight per bushel, it was actually the best up to that time; but, as will be seen, it has been exceeded on this point in several seasons since. In quantity of straw it was also over average. As in the case of wheat, the season was peculiarly favourable for the action of ammonia salts—indeed, for all high manuring—the farmyard manure giving not only considerably more than average total produce, but, both as to quantity and quality of corn, a better result than in any other season hitherto. Without manure, or with purely mineral manure, the amount of produce of both corn and straw has been exceeded in several seasons; but with mineral and nitrogenous manures together, the only years that exceeded or closely approached 1863 were, in produce of corn, 1854, 1857, and 1864; but, in produce of straw, 1854 the most strikingly, and less so 1855, 1861, 1862, 1864, 1869, and 1871.

A comparison between the characters of the seasons of 1854 and 1863, the former yielding, with high manuring, generally fully as much or more corn, and considerably more straw, than the latter, will usefully illustrate upon what conditions the very favourable, but still very different results of the two seasons depended. In 1854, which gave much the larger quantity of total produce of barley (corn and straw together), the winter having been very severe, the land was worked and the seed was sown very early; there was considerably less than half the average amount of rain in March, April, June, and July, with nearly double the usual amount in May. In 1863, on the other hand, the seed was not in so early; there was only about half the usual amount of rain in March, April, May, and July, with nearly double the usual amount in June. In both years there was in August about the average amount of rain. Almost throughout the six months enumerated, 1863 was slightly the warmer of the two, though both were rather warmer than usual in the early spring, and rather cooler than usual, but with a dry atmosphere, in the summer. Thus, both seasons were, throughout the greater part of the period of growth, comparatively dry and temperate; but each had, at one period, a large fall of rain, which, in 1854, yielding the largest amount of total produce, came in May, whilst in 1863 it did not come until June. It is worthy of

remark, that with the winter-sown wheat the result was reversed ; for with it the larger produce of both corn and straw—indeed the largest ever obtained—was in 1863. The difference is, however, explicable by the very different characters of the winters in the two cases. The winter of 1853-4 was unusually severe, and the wheat-plant backward in the early spring ; whereas the winter of 1862-3 was mild, with a good deal of rain in January, and the plant was very forward in the spring. It would, therefore, the less require liberal rains before June than the spring-sown barley, and would be in a better state for benefitting by the generally favourable climatic conditions of the spring and summer than the less forward wheat-plant of 1854.

Thirteenth Season, 1864.

October, November, and December, 1863, were warmer than usual, with about, but upon the whole, less than the average amount of rain. January and February, 1864, though including some abnormally warm intervals, embraced longer periods of very cold and wintry weather, which checked forward vegetation ; there was considerably less than the average fall of rain in January, and a very small fall, including snow, in February. In March the rainfall was large—the first half of the month generally warm, the latter half cold—and, upon the whole, the quarter had been very variable, colder than usual, with many alternations from frost to thaw. April and May were, for the most part, warm, with less than the average amount of rain ; but the end of May and nearly the whole of June were comparatively cold, but with little rain. There was very unusually little rain in July and August, but an excess in September. The day-temperatures generally ranged high in July, but about the average in August and September ; whilst the night-temperatures were somewhat below the average in July, much below in August, and about the average in September. In June and July the dew-point was below, and in August very much below, the average. The degree of humidity of the air was in June low, in July about the average, and in August very remarkably below the average.

Thus, the winter was very variable, including a good deal of warm, but also much very cold and wintry weather, though with comparatively little rain. The spring, though changeable and wet at the beginning, was, upon the whole, warm and dry ; June was cold and dry, whilst the rest of the summer was hot in the day and cold at night, with very little rain, and in August especially a very dry atmosphere.

The wheat crop of the country proved to be, in quantity, much above the average on good soils, but below the average on poor

soils, and in quality generally above the average. Barley was reported to be very unequal—good on good soils, stunted and poor on light soils—and, owing to the summer drought, the early generally much better than the late sown; upon the whole, however, over average. Oats irregular, short, deficient in yield, and generally much below average in quantity. Roots generally a failure.

The experimental wheat crop, though by no means equal to the extraordinary one of 1863, was nevertheless considerably above the average both in quantity and quality of grain, especially under liberal manuring; it was also much above the average in quantity of straw. The following results were obtained in the experimental barley field:—

TABLE XIV.—Quantity and Quality of Barley on Selected Plots.
Thirteenth Season, 1864.

Plots.	MANURES, PER ACRE.	PRODUCE PER ACRE, &c.					
		Dressed Corn.		Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn to 100 Straw.
		Quantity.	Weight per Bush.				
		Bushels.	lbs.	lbs.	Cwts.	lbs.	
7	14 Tons Farmyard Manure	62	57·4	3672	37½	7852	87·8
1 O	Unmanured	24	55·7	1379	12½	2809	96·4
4 O	Mixed Mineral Manure ..	33½	57·3	1949	16½	3829	103·7
1 A	200 lbs. Ammonia-salts ..	38½	55·4	2258	20½	4533	99·2
4 A	Mixed Mineral Manure, and 200 lbs. Ammonia-salts ..	55½	57·6	3316	34½	7225	84·8
4 A A	Mixed Mineral Manure, and 200 lbs. (¹) Ammonia-salts ..	56½	57·6	3299	37½	7469	79·1
4 C	Mixed Mineral Manure, and 1000 lbs. (²) Rape-cake ..	53	57·2	3153	34½	7061	80·7

(¹) 400 lbs. the first 6 years (1852-7).

(²) 2000 lbs. the first 6 years (1852-7).

The seed was sown on March 26th, the most forward plots were cut on August 11th, and carted on August 13th; and the remainder cut on August 17th, and carted on August 18th. The sowing was, therefore, rather late; but, with a hot and dry ripening period, the harvest was moderately early. There had been a good deal of rain in March; but, from that time up to harvest, very little. With the exception of June, which was cold, the spring and summer were generally warm, and the ripening period characterized by a very dry atmosphere. Notwithstanding the prevailing warmth and dryness of the growing periods, all the experimental plots gave very considerably more, of both corn and straw, than the average. Of corn there was generally more than in any other year of the 20, excepting 1863 and 1854; and with farmyard manure, by the use of which there is

so much accumulation in the soil, more than in any year of the 20. The weight per bushel was also much above the average; throughout higher than in 1863, with few exceptions as high as, and in some cases higher than, in any other year. The experimental barley crop was, therefore, one of large produce of straw, indicating considerable luxuriance of growth; of exceptionally large produce of grain, which was of very exceptionally high quality. It is probable that, with the wet March, the plant found sufficient moisture in the soil for the requirements of its early growth; that, owing to the distribution of the comparatively small total fall during the rest of the season, it was sufficient under those preliminary conditions; that the low temperature of June prevented over luxuriance; that the cold nights, alternating with the hot days, of July, prevented premature ripening; and that the dry atmosphere during the final stages contributed to the high perfection of the grain.

These very favourable results in the experimental field are not inconsistent with the record of the barley crops in the country at large; for, though it was admitted that on light soils, and where sown late, the crop was very poor, it was equally admitted that, under more favourable conditions in these respects, it was very good.

Fourteenth Season, 1865.

After a rather wet September, but a very low aggregate rainfall during the first 9 months of the year, the concluding quarter of 1864 was also characterized by less rain than usual. The deficiency was very considerable in October and December, though there was rather an excess in November. As to temperature, the period was very variable, with a good deal of cold weather. There were occasionally very high winds; whilst the degree of humidity of the air was very unusually low in October, and somewhat low in November and December also. In January, 1865, there was a considerable, and in February a slight excess, but in March a deficiency of rain (including snow); though, throughout the quarter, the number of rainy days was small. Excepting the first half of January, the greater part of which was warm, the quarter was almost throughout unusually stormy and cold, with a good deal of snow; March in particular was generally very exceptionally cold and inclement. In April and June very little rain fell; whilst in May and July there was an excess, and in August a very great excess. In September, however, the fall was very exceptionally small. April, May, and the beginning of June, were much warmer than the average, but the remainder of June was variable, and, upon the whole, rather cold. The mean temperature of the

quarter, and especially of April, was, however, the highest on record for that period of the year; and the air was pretty uniformly much drier than the average; the rain which fell being little distributed, coming for the most part in heavy showers. July, with an excess of rain, was also warmer than usual. The greater part of August was not only extremely wet, but rather colder than usual; whilst September was both the driest and hottest on record; completing, notwithstanding the comparatively low temperature of August, a hotter period of 6 months than any other known. In each month, too (excepting August, when it was very high), the degree of humidity of the air was generally very low.

The winter of 1864-5, though variable, was, therefore, upon the whole, very cold, stormy, and inclement; the early spring unusually cold and backward; but the remainder, and greater part, was very warm, with a dry atmosphere; though, towards the end, some heavy rains fell, and the combined conditions brought the crops very rapidly forward. June was also dry, hot at the beginning, though afterwards comparatively cool; July was hot, with a good deal of rain, but, upon the whole, a dry atmosphere; the greater part of August was cool and very wet, but the remainder, and September, very hot and dry, favouring the rapid completion of the hitherto much retarded harvest work. Thus, after a severe winter and late spring, the growing period was characterized by great heat, dryness of atmosphere, and a deficient amount and distribution of rain; the ripening period by an excess of rain, followed, however, by an eventually favourable, though late harvest time.

The wheat crop of the country was reported to be very variable; good on clays and land in good condition, but poor on light and badly farmed soils; in the aggregate about, or slightly under, average as to quantity; variable, and, upon the whole, only moderate in quality. Barley was said to be the best of the cereals, but inferior on light lands; oats the poorest crop for many years past.

The experimental wheat crop was, in quantity of corn, much below the average on the poorly manured, but considerably above it on the highly manured plots. The weight per bushel of dressed corn was, throughout, above the average; but the quantity of straw was almost throughout considerably below average, though proportionally the less so the higher the manuring. The results obtained in the experimental barley-field are shown in Table XV. (p. 46).

The wintry weather of March delayed all spring sowing, and the experimental barley was not put in until April 6th. On the other hand, the prevailing heat and drought of the spring and summer, brought grain crops early forward, and the whole of the

TABLE XV.—Quantity and Quality of Barley on Selected Plots.
Fourteenth Season, 1865.

Plots.	MANURES, PER ACRE.	PRODUCE PER ACRE, &c.					
		Dressed Corn.		Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn to 100 Straw.
		Quantity.	Weight per Bush.				
		Bushels.	lbs.	lbs.	Cwts.	lbs.	
7	14 Tons Farmyard Manure	52½	54·4	2923	25½	5769	102·7
1 O	Unmanured	18	53·9	1018	8½	1924	112·3
4 O	Mixed Mineral Manure ..	24½	54·0	1349	10	2464	121·0
1 A	200 lbs. Ammonia-salts ..	29½	53·8	1666	13	3127	114·0
4 A	Mixed Mineral Manure, and 200 lbs. Ammonia-salts ..	46½	53·5	2549	22½	5075	100·9
4 A A	Mixed Mineral Manure, and 200 lbs. (¹) Ammonia-salts ..	48½	53·3	2684	24½	5469	96·4
4 C	Mixed Mineral Manure, and 1000 lbs. (²) Rape-cake ..	48½	53·5	2648	22	5117	107·2

(¹) 400 lbs. the first 6 years (1852-7).

(²) 2000 lbs. the first 6 years (1852-7).

barley was cut on August 9th; but, owing to the wet weather which had then set in, it was not carted until August 18th. As might be expected from the characters of the season, and as was consistent with the results obtained in the experimental wheat field, there was throughout a considerable deficiency of total produce (corn and straw together), which was proportionally the greater the poorer the conditions as to manuring. There was, however, a very high proportion of corn to straw, the higher the poorer the manuring; and the weight per bushel of dressed corn was about the average. As to the actual amount of corn per acre, it was, without manure, with mineral manure alone, and with ammonia-salts alone, considerably below the average, but much nearer the average with the more complete manuring. The result is, then, that with a deficiency in total amount of rain, the very unequal distribution of that which fell, the very dry atmosphere, and the unusually high temperatures almost throughout the periods of growth, the conditions above ground were adverse to luxuriance, but very favourable to seeding tendency and maturation; and, where the conditions supplied within the soil were the most defective, the root-range would doubtless be the most restricted, and the plants would suffer the most; whereas, where the conditions supplied within the soil were liberal, a more extended root-range would render the plant less sensitive to the atmospheric heat and drought; and, hence, proportionally less failing in luxuriance.

The characters of both the experimental wheat and experimental barley-crops were, therefore, in the main accordant with those of the respective crops in the country at large. That is,

the results in the experimental fields varied greatly according to the conditions of manuring; the crops suffering most where the conditions of manuring were the most defective, whilst it was on the light and badly farmed lands that the crops of the country suffered most. On the other hand, it was under the influence of liberal manuring that the quantity of corn was proportionally the highest in the experimental fields, and it was on the clays, and better farmed lands, that the crops were good in the country generally.

Fifteenth Season, 1866.

The very warm and dry weather of September, 1865, extended through the first week of October; and, although there were a few cold intervals, the temperatures of the three concluding months of the year ruled higher than the average; December, especially, being unusually warm. The period included, however, very great fluctuations in barometric pressure, and some extremely severe storms of wind; whilst in October a very excessive, in November a full, but in December a deficient, amount of rain fell. January and the first half of February (1866) were also unusually warm, though in January there was a heavy fall of snow, which, however, rapidly thawed, and the whole period was very wet. A cold and drier period then set in, and extended to the middle of March, checking the hitherto much too forward vegetation; and then, to the end of the quarter, the temperatures, though variable, ruled, upon the whole, very high, and there was a full amount of rain. The beginning of April was cold and rather wet, and the remainder considerably warmer and drier than the average. May was, throughout, unusually cold both day and night, and there was a deficiency of rain. June was changeable, but included a good deal of hot weather, which raised the mean temperature above the average, and during the month a considerable excess of rain fell. The beginning of July was cold and wet; then followed a week of hot and dry weather; but, from about the middle of the month to nearly the end of September, the weather was, with the exception of few and short intervals, generally cold, with a good deal of rain and wind in August, and an almost continuous and considerably excessive fall in September. October was, however, upon the whole, warmer and drier than usual. In June, July, August, September, and October, the degree of humidity of the air was generally high.

Thus, after a very wet and comparatively warm autumn, the winter was, until the middle of February, unusually warm, with a great deal of rain, inducing premature luxuriance of grass and winter-sown crops; then came a month of cold and dry weather,

checking growth. The remainder of the spring was at first very variable, but May was unusually cold and dry. The early summer was changeable, but mostly warm, with a good deal of rain; and the ripening and harvest periods were almost continuously cold and rainy, with a moist atmosphere, but with occasional high and drying winds.

After the winter the wheat-plant was very forward, but was much checked by the prevailing, though not continuous, coldness and dryness of the spring. Recovering, and showing fair promise in early summer, it was again checked by the sunless weather, and in many cases laid and damaged by the wet maturing and harvest period. The harvest was protracted and late; and the crop was eventually pronounced to be below an average in quantity, though of fair quality. Barley and oats were said to be very variable; in some cases poor, in others much damaged; but, upon the whole, above average in quantity, and in some districts harvested in good condition, and of good quality.

The experimental wheat-crop was, under all conditions of manuring, below the average in quantity of corn; and, excepting under the highest manuring (when it was considerably above), below the average in quantity of straw also. The weight per bushel was, however, over average. The following results were obtained in the experimental barley-field:—

TABLE XVI.—Quantity and Quality of Barley on Selected Plots.
Fifteenth Season, 1866.

Plots.	MANURES, PER ACRE	PRODUCE PER ACRE, &c.					
		Dressed Corn.		Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn to 100 Straw.
		Quantity.	Weight per Bush.				
		Bushels.	lbs.	lbs.	Cwts.	lbs.	
7	14 Tons Farmyard Manure	53½	54·9	3065	31½	6594	86·8
1 O	Unmanured	15½	51·1	858	9½	1928	80·1
4 O	Mixed Mineral Manure ..	24	52·7	1323	12½	2759	92·1
1 A	200 lbs. Ammonia-salts ..	27½	50·9	1474	15½	3200	85·4
4 A	Mixed Mineral Manure, and 200 lbs. Ammonia-salts ..	47	54·7	2636	27½	5704	85·9
4 A A	Mixed Mineral Manure, and 200 lbs. (†) Ammonia-salts	50½	55·4	2954	28½	6117	93·4
4 C	Mixed Mineral Manure, and 1000 lbs. (†) Rape-cake ..	48½	55·6	2834	27½	5929	91·6

(†) 400 lbs. the first 6 years (1852-7).

(†) 2000 lbs. the first 6 years (1852-7).

The seed was not sown until April 2nd. The whole of the plots were cut on August 15th, 16th, and 17th; the earliest were carted on August 18th, but the remainder not until August 23rd and 24th. With, upon the whole, a dry and backward spring; a changeable, but mostly warm and wet, early summer;

but cold, wet, and windy ripening and harvest period, the result was considerably less than the average produce of both corn and straw without manure, and with defective manuring; but fully average quantity of corn, and not much less than average quantity of straw, with the more liberal artificial manuring. The farmyard manure, indeed, gave more than its average of both corn and straw; but, as will be seen further on, the produce on the farmyard manure plot increased very much during the later years of the experiment, so that the result must not be attributed exclusively to the season. The weight per bushel of dressed corn is seen to vary very considerably under the different conditions of manuring. Thus, without manure, and with ammonia-salts alone, the weight per bushel was considerably below the average under those conditions; whilst, with the more complex and more perfect artificial manures, and with the farmyard manure—that is with the more liberal soil-conditions—it was considerably above the average.

The smaller deficiency, if any, in total produce, and the higher quality, under high manuring, and the greater deficiency, and the poorer quality, under the poorer soil-conditions, are consistent with the results obtained in the experimental wheat-field, and also consistent with the character of great diversity given of the spring-sown crops of the country at large.

The season of 1866, with its late spring, its warm and wet early summer, but prevailing cold and wet later growing and ripening periods, gave considerably greater bulk of produce than 1865, with its also late spring, but warm and dry growing period. Though both seasons were unfavourable, they were essentially different in character. Yet they agree in this: that each was relatively less unfavourable with high than with poor manuring. The more perfect soil-conditions enabled the plant the better to withstand the heat and dryness in 1865, and the prevailing cold and wet of the growing and ripening period in 1866. That the quality of both wheat and barley was not worse in 1866, notwithstanding the cold and wet ripening period, was greatly due to the drying winds which alternated with the rains; but the much higher, indeed, the really high quality of the barley grown by liberal manuring, shows how much more vital power the plants growing under the more favourable soil-conditions possessed, and that in a certain degree those conditions compensated for the lacking favourable atmospheric conditions.

Sixteenth Season, 1867.

Though including some cold intervals, the concluding quarter of 1866 was generally warmer than the average, with somewhat

less than the usual aggregate amount of rain, though a good deal fell within a short interval about the middle of November, causing floods, and hindering autumn sowing in some localities. In January, 1867, the fluctuations were very great; extreme cold and heavy falls of snow, alternating with rapid thaws, warm weather, heavy gales, and a good deal of rain. The last week of January, and almost the whole of February, were very unusually warm, with a large amount of rain at the beginning, and a moderate quantity over the rest of the period. March, again, was almost to the conclusion very cold and wintry, with a good deal of snow. Throughout the quarter there was a succession of gales of wind. Owing to the severe weather of March, the growth of winter-sown crops was checked; and owing partly to the wetness, and partly to the frost, the preparation of the land for spring-sowing was much retarded. April, and the beginning of May, were very unsettled; stormy, rainy, and changeable as to temperature; but, on the average, warmer than usual. Later in May, besides some very warm, there was a longer period of extremely cold weather, with a dry atmosphere, and frosty nights, much checking vegetation; though, during the month, there was rather more than the average fall of rain. June was comparatively dry, very changeable as to temperature, but on the average colder than usual. The cold weather continued throughout July and the beginning of August, and the period was generally sunless and cloudy, with an excess of rain in July, which fell very heavily towards the end of the month, and much laid, and in some cases inundated, the crops. The remainder of August, and September, were much finer, rather warmer than the average, though with rather more than the average fall of rain; which, however, was not much distributed, but fell for the most part in considerable quantities at a time.

Thus, the early winter was, upon the whole, warmer and drier than usual; then came intervals of severe frost, snow, and heavy gales, followed by several weeks of very warm weather, with a good deal of rain. The early spring was very wintry and stormy, and both growth and spring-sowing were retarded. The remainder was very changeable as to temperature; at first warmer, afterwards very unseasonably cold, and throughout frequently stormy and rainy. The rest of the growing, as well as the early ripening period, was changeable, though for the most part unseasonably cold, cloudy, and sunless, with a great deal, and some very heavy falls, of rain, which much laid the crops. The harvest-time, though late, and including some heavy rains, was, however, upon the whole, not unfavourable for the greater portion of the Midland, Southern, and Eastern districts.

With a wet autumn, a winter alternately very mild and very severe, a spring with alternations of extreme heat with cold, frost, and wet, and a summer with a good deal of sunless weather, with occasional violent storms of wind and rain, much laying the crops, were not conditions from which a productive harvest might be expected. Yet, both before and after the favourable change at harvest time, some writers in the 'Times' gave very sanguine views of the crops of the country at large. The records in the agricultural papers were, however, much less favourable; and the results obtained at Rothamsted led to the conclusion that the general wheat-crop would be not less than 20 per cent. below an average. Subsequent experience showed that this unfavourable estimate was only too well founded. Spring crops were almost everywhere sown late, especially on heavy lands. Barley was said to have suffered a good deal from the frosts of May, but at harvest the crop was reported to be but little under average in quantity, though variable in quality. Oats were considered to be over average.

The experimental wheat crop was very deficient in straw, and, upon the whole, more deficient in quantity of corn than in any year since 1853; though the quality of the grain was even over average. The following results were obtained in the experimental barley-field:—

TABLE XVII.—Quantity and Quality of Barley on Selected Plots.
Sixteenth Season, 1867.

Plots.	MANURES, PER ACRE.	PRODUCE PER ACRE, &c.					
		Dressed Corn.		Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn to 100 Straw.
		Quantity.	Weight per Bush.				
		Bushels.	lbs.	lbs.	Cwts.	lbs.	
7	14 Tons Farmyard Manure	45½	54·8	2614	27½	5652	86·1
1 O	Unmanured	17½	51·8	978	10½	2124	85·3
4 O	Mixed Mineral Manure ..	20½	53·6	1180	12	2526	87·7
1 A	200 lbs. Ammonia-salts ..	30½	51·3	1686	17½	3611	87·6
4 A	Mixed Mineral Manure, and 200 lbs. Ammonia-salts }	43½	54·3	2454	25½	5304	86·1
4 A A	Mixed Mineral Manure, and 200 lbs. (¹) Ammonia-salts }	45	54·6	2573	28½	5753	80·9
4 C	Mixed Mineral Manure, and 1000 lbs. (²) Rape-cake .. }	42½	54·8	2411	24½	5121	89·0

(¹) 400 lbs. the first 6 years (1852-7).

(²) 2000 lbs. the first 6 years (1852-7).

Owing to the alternate wet and frost, and the consequent unworkable condition of the land, the experimental barley was again sown late, not being put in until April 5. The earlier plots were cut on August 20 and 21, the later not until August

27 and 28, and the whole were carted on August 31. The earlier and better crops, those grown by manures containing nitrogen and superphosphate, and by farmyard manure, were the most laid. Notwithstanding this, owing to the improved weather at the final ripening, and harvest time, it was just these crops that gave a rather better than average weight per bushel of corn, whilst the poorer and more backward crops gave lower than the average weight per bushel. The quantity of both corn and straw was throughout lower than the average, and the deficiency was proportionally the greater the relative deficiency of available nitrogen within the soil; that is to say, without manure, and with purely mineral manure. The proportion of corn to straw was generally not far from the average, and, under some of the best conditions of manuring, somewhat over the average. Upon the whole, therefore, the experimental barley crop was deficient in quantity, but of full average quality. The deficiency in the spring-sown crop was, however, much less than that of the experimental wheat; and less, perhaps, than might have been expected considering the late sowing, the alternations of forcing and checking conditions of weather during the earlier stages, and the sunless character of the later periods of growth. The result is, at the same time, consistent with that recorded of the barley-crop of the country, which, according to the more reliable authorities, suffered considerably less than wheat; it is also consistent in showing relatively less deficiency the better the soil-conditions.

Seventeenth Season, 1868.

October, 1867, was very variable as to temperature, upon the whole colder than usual, with comparatively little rain, but occasional high winds. There was very unusually little rain in November, and the weather was for the most part clear but cold, and very favourable for working the land and sowing. December was characterised by great and rapid variations of temperature and barometric pressure, some extremely heavy gales, sometimes frost, snow, and sleet, at others very warm weather; in the aggregate there was a full amount of rain, and throughout the month agricultural operations were much impeded. The first eleven days of January, 1868, were very cold; but from that time to the end of the quarter (indeed to the end of the summer), the weather was unusually warm. There was a considerable excess of rain, and there were several gales of wind, in January; but there were only moderate amounts of rain in February and March. In these months vegetation became very

forward, and the weather was generally favourable for working the land and for spring sowing. April, May, and June, again, were all considerably warmer than the average. The average temperature of April had however frequently, and that of each of the other months occasionally, been exceeded in the corresponding months of other years; but the average temperature of the three months together had only once been exceeded in any corresponding three months for 98 years (the period for which records are available), namely, in 1865, when, though April was hotter, May and June were not quite so hot as in 1868; and the average temperature of the whole period, from the middle of January to the end of June, was only exceeded in 1822. Concurrently with this long-continued warm weather, there was, as already said, a great excess of rain in January, and only moderate amounts in February and March; there was a small excess in April, a deficiency in May, and a very great deficiency in June. Temperatures in excess of the average also prevailed almost continuously throughout the succeeding quarter, namely, to the end of September. July, in particular, was very excessively warm, with at the same time a continued great deficiency of rain; August was also warmer than the average, but with a good deal of rain; and September more in excess as to temperature than August, with a deficiency of rain. In no year of the previous 98 had the temperature so far exceeded the average in so long a corresponding period as that from the middle of January to the end of September of this year, 1868. The total rainfall of the nine months was not much below the average; but the amount which fell was very excessive in January, and excessive also in April and in August, whilst it was deficient in each of the other months of the period, and very greatly so during the three consecutive months of greatest heat, namely May, June, and July. The degree of humidity of the atmosphere was also lower than the average in each of the nine months from January to September inclusive, greatly so in June, very greatly so in July, and considerably in August and September.

The characters of this extraordinary season may be briefly summarised as follows:—After a favourable autumn seed-time, the first half of the winter was very variable, including some very warm, but more stormy, wet, snowy and frosty weather. From that time to after harvest, the temperature was almost always above the average, and very greatly so in the summer months of June and July; whilst, after a favourable spring seed-time, there was a sufficiency of rain in April to give a fair start to early-sown crops; but, from that time until the harvest was nearly over, throughout the Midland, Southern, and Eastern districts of the country, the excessive temperatures were accompanied by a drought of unusual severity, both as regards the length of its

duration, and the great amount of the deficiency of rain, with at the same time a very dry atmosphere.

With the favourable autumn seed-time, the area under wheat was over average. In the spring the plant was generally good, the harvest was very early, and finally the crop was reported to be considerably over average in both quantity and quality on good and well farmed soils; on light and poorly farmed land, on the other hand, the crop suffered much from the heat and drought. Still, the aggregate wheat crop of the country was supposed to be about 20 per cent. over average in quantity, and of over average quality. Naturally, spring-sown crops suffered much more from the heat and drought than wheat. Barley was, however, said to yield well, and be of good quality, on deep and well-farmed lands, and when sown early, but to be very deficient when sown late, or on shallow soils; and to be so on many of the usually good barley lands. Oats suffered more than barley, and were almost universally reported to be under average, and in many cases a complete failure.

The produce in the experimental wheat field was, under all conditions of manuring, over average in quantity, but proportionally much more so with high than with low manuring. The weight per bushel of dressed corn ranged from 3 to 5 lbs. over the average. The quantity of straw was considerably below the average with low manuring, but average, or over average, with high manuring. The proportion of corn to straw was also generally over average, but proportionally the less so the higher the manuring and the greater the bulk of the crop. The following results were obtained in the experimental barley-field:—

TABLE XVIII.—Quantity and Quality of Barley on Selected Plots.
Seventeenth Season, 1868.

Plots.	MANURES, PER ACRE.	PRODUCE PER ACRE, &c.					
		Dressed Corn.		Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn to 100 Straw.
		Quantity.	Weight per Bush.				
		Bushels.	lbs.	lbs.	Cwts.	lbs.	
7	14 Tons Farmyard Manure	43½	57·1	2539	24½	5281	92·6
1 O	Unmanured	15½	54·3	873	11½	2173	67·2
4 O	Mixed Mineral Manure ..	17½	55·3	998	10½	2126	88·5
1 A	200 lbs. Ammonia-salts ..	20½	53·3	1136	12½	2507	82·9
4 A	Mixed Mineral Manure, and 200 lbs. Ammonia-salts ..	34½	55·6	1978	20½	4311	84·8
4 A A	Mixed Mineral Manure, and 275 lbs. Nitrate Soda ⁽¹⁾ ..	45½	56·0	2566	25½	5454	90·2
4 C	Mixed Mineral Manure, and 1000 lbs. ⁽²⁾ Rape-cake ..	36½	55·4	2051	21½	4414	86·8

⁽¹⁾ 400 lbs. Ammonia-salts the first 6 years (1852-7), 200 lbs. the next 10 years (1858-67); 275 lbs. Nitrate Soda, 1868, and since.

⁽²⁾ 2000 lbs. the first 6 years (1852-7).

Unfortunately, the seed was not put in until March 20 ; and with, excepting in April, a great deficiency of rain from that time until harvest, and, at the same time, unusually high temperatures and dry atmosphere, the crop was, for the locality, very early cut, namely, on July 31, and it was carted on August 5. The deficiency of both corn and straw is throughout very considerable, but proportionally the greater the more defective the manuring. Thus, compared with the average of the twenty years in each case, the deficiency of total produce, corn and straw together, was with farmyard manure only about one-tenth, with mixed mineral manure and ammonia-salts (4 A), and with mixed mineral manure and rape-cake, about one-fourth, but with mineral manure alone, or ammonia-salts alone, about one-third. Further, in these cases of the more defective manuring, and the more deficient total crop, the proportion of corn to straw is below the average, whilst, with the nitrogenous and mineral manure together, as well as with farmyard manure, the proportion of corn to straw is rather higher than the average. Deficient as was the quantity, the quality was, however, in all cases high ; and the higher the more liberal the conditions of manuring. Thus, the weight per bushel was between 55 and 56 lbs. with the mixed mineral manure and ammonia-salts, and with the mixed mineral manure and rape-cake, and was over 57 lbs. with farmyard manure.

It will be borne in mind that, during the first six years of the twenty (1852-1857), plot 4 A A had annually twice as much ammonia-salts as 4 A, but that, during the next ten years (1858-1867), only the same quantity of ammonia-salts was applied as on 4 A, namely, 200 lbs. per acre per annum ; and reference to the tables will show that there has continued to be some excess of produce on 4 A A, as compared with 4 A, due to the unexhausted residue from the excessive supply during the first six years. For the year 1868, and subsequently, however, an amount of nitrate of soda, containing the same quantity of nitrogen, has annually been substituted on plot 4 A A for the 200 lbs. of ammonia-salts applied during the previous ten years ; and it will be seen that, in this year of drought, the plot with the nitrate gives nearly 11 bushels more corn, and about 5 cwts. more straw, than the plot with an equivalent quantity of nitrogen as ammonia-salts. This amount of excess is much greater than has been obtained in any succeeding year hitherto ; though in 1870, which was also a year of drought, the excess of produce with the nitrate was again very considerable.

In a paper in the ' Journal of the Royal Agricultural Society

of England,* we showed that the soil of the plot in the experimental wheat-field which had then been manured with 14 tons of farmyard manure per acre per annum for twenty-five years in succession, owing to its vast accumulation of organic matter, and greater degree of disintegration, porosity, and power of absorption, retained, near the surface, very much more water than that of either the closely-adjointing unmanured, or an artificially manured plot in the same field.

In the same paper we recorded the fact, that a plot of permanent meadow-land which received annually mixed mineral manure, and a given amount of nitrogen as ammonia-salts, yielded in the season of drought of 1870, 23 cwts. of hay less than its average; whilst, another plot, receiving annually the same mineral manures, and the same amount of nitrogen, but in the form of nitrate of soda instead of ammonia-salts, yielded, in the same season of drought, only $1\frac{1}{2}$ cwt. of hay less than its average amount, and about $26\frac{3}{4}$ cwts. more than the plot manured with the same mineral manure and the same amount of nitrogen as ammonia-salts.

This result was assumed to be connected with the difference in the character of the two nitrogenous manures (ammonia-salts and nitrate of soda), in regard to their reactions upon the soil, and the consequent degree of rapidity and range of distribution of them, or their products of decomposition, within it;—the nitrate, or its products of decomposition, becoming much more rapidly distributed, and washed into the subsoil, whither the roots follow it. On examination it was found—that certain plants of the mixed herbage, having roots of a characteristically downward tendency, were much more prevalent on the plot manured with nitrate of soda, than on that manured with ammonia-salts; that the subsoil of the nitrated plot was disintegrated and permeated by roots to a much greater depth; and that, accordingly, the lower layers of the subsoil had been pumped much drier by the action of roots, than the corresponding layers of the plot manured with ammonia-salts.

These very interesting and significant facts point to the explanation of the much less prejudicial influence of the drought of 1868 on the experimental barley-crops grown by farmyard manure, and by mineral manure and nitrate of soda, than on those grown by mineral manure and ammonia-salts. In the case of the farmyard-manure plot, the result was probably due to the great amount of moisture taken up, and retained, by the upper layers of the soil, from the winter and early-spring rains. In that of the nitrated plot it was, it is true, the first year of the application;

* Vol. vii.—s.s. Part I.—“Effects of the Drought of 1870 on some of the Experimental Crops at Rothamsted.”

but, with the fair amount of rain in March, and the full amount in April, it is still probable that there would be a considerable distribution of the manure, and, accordingly, an increased disintegration, and porosity of the subsoil, and retention of moisture by it; the combined conditions leading to a correspondingly greater distribution of the roots in the lower layers, by virtue of which the plants would obtain possession of a greater range of soil, and an increased supply of moisture within it. In the one case, therefore, it was the resources of moisture in the upper layers of the soil, and in the other those in the lower layers, that rendered the growing crop more independent of the supplies from external sources.

In conclusion, the difference of effect of the excessive summer heat and drought on winter and spring-sown crops, and on crops grown on deep and on shallow soils, was very striking. Thus, the experimental wheat-crop indicated a produce about 20 per cent. over the average, and the wheat-crop of the country at large was extremely good on good soils, though very poor on poor soils, yet was supposed to yield in the aggregate 20 per cent. over an average. The rather late-sown experimental barley, on the other hand, gave a produce from one-tenth to one-third below the average, according to the manure employed; and the barley-crop of the country was good when sown early on deep soils, and very deficient when sown late on shallow soils, but gave in the aggregate a considerably deficient crop. The great protection against the injurious effects of summer drought, which the early sowing of spring-crops gives, by enabling the plant to obtain possession of a more extended root-range, was thus, in this season, strikingly illustrated.

Eighteenth Season, 1869.

The extraordinarily warm period of nearly nine months duration ended with September, 1868. October and November were throughout, with very few exceptions, colder than usual, both day and night; whilst in October there was a deficiency of rain, and in November a very great deficiency. December, on the other hand, was almost throughout very much warmer than the average, with a very great excess of rain, some violent gales of wind, very variable, but, upon the whole, very low barometric pressures, and high degree of humidity of the atmosphere. The average temperature of December had, indeed, been exceeded only twice during the preceding ninety-eight years; namely, in 1806 and 1852. With the exception of a week after the middle of January (1869), the very warm period continued until the end of February, completing three winter months of average

temperature about 6 degrees higher than the average of ninety-eight years. There was, again, considerable excess of rain in January, and a slight excess in February. March, on the contrary, was several degrees colder than the average, with about, or less than, the average amount of rain. Early in April warm weather set in, and lasted till nearly the end of the month, the temperature during this period being several degrees higher than the average, whilst the fall of rain was generally under the average. May and June were, with few exceptions, of short duration, very much colder than the average. Towards the end of May the cold was very extreme for the season, and the greater part of June was very unusually cold, both day and night; and in May there was a considerable excess, though in June a deficiency, of rain. Early in July there was again a change to warm weather, which lasted till the end of the month, during which there was very little rain. The first three weeks of August were very unseasonably cold and showery, though the total amount of rain was comparatively small; but the concluding week of the month was very bright and hot. Then came a short period of cold weather, but the remainder of September was warm but stormy, with a good deal of rain. In April, May, and June, the degree of humidity of the air ranged high, especially in May; in July it was about the average, but in August and September it was below it.

To sum up the characters of the season: The heat and drought of the spring and summer of 1868 were followed by a warm and dry September, but cold and dry October and November, providing a good autumn seed-time. The three winter months were very warm, and, December and January especially, very wet, bringing autumn-sown crops very rapidly forward, and providing an unusual amount of winter grazing, which greatly compensated for the previous deficiency. But, owing to the condition of the land, spring sowing was retarded. The weather in March was dry and cold, much checking vegetation; which, however, recovered rapidly under the influence of very warm, though somewhat dry, weather in April; but the remainder of the spring was very cold, and also wet; June, again, for the most part cold; July warm, most of August cold, the conclusion, and September, hot; whilst the summer was comparatively dry, though the harvest-time somewhat unsettled.

With a season characterised by alternate periods of forcing and checking weather, with more of the latter than of the former during the time of most active growth, and with a changeable ripening and harvest period, favourable or unfavourable for the

crops according to their forwardness at the time, the reports of the crops of the country generally were very conflicting. The wheat-crop, though very variable, was reported to be, in the aggregate, somewhat below an average, both in quantity and quality. The barley-crop was also very variable, but, perhaps, upon the whole rather better than wheat. Oats were more uniformly bad.

In accordance with the characters of the crop of the country, the experimental wheat-crop was very variable; much below the average under most conditions of manuring, but above it under others; and particularly so with farmyard manure, and the mixture of mineral manure and nitrate of soda—a point to which further reference will be made presently. The results in the experimental barley-field were as follows:—

TABLE XIX.—Quantity and Quality of Barley on Selected Plots.
Eighteenth Season, 1869.

Plots.	MANURES, PER ACRE.	PRODUCE PER ACRE, &c.					
		Dressed Corn.		Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn to 100 Straw.
		Quantity.	Weight per Bush.				
		Bushels.	lbs.	lbs.	Cwts.	lbs.	
7	14 Tons Farmyard Manure	46½	56·4	2746	28½	5959	85·5
1 O	Unmanured	15½	52·4	840	11	2075	68·0
4 O	Mixed Mineral Manure ..	22½	54·6	1286	12½	2729	89·2
1 A	200 lbs. Ammonia-salts ..	27½	52·4	1599	18½	3640	78·4
4 A	Mixed Mineral Manure, and 200 lbs. Ammonia-salts ..	49½	57·4	2848	34½	6701	73·9
4 A A	Mixed Mineral Manure, and 275 lbs. Nitrate Soda (¹) ..	40½	57·1	2929	38½	7194	68·7
4 C	Mixed Mineral Manure, and 1000 lbs. (²) Rape-cake ..	52½	57·4	3065	35½	7001	77·9

(¹) 400 lbs. Ammonia-salts the first 6 years (1852-7), 200 lbs. the next 10 years (1858-67); 275 lbs. Nitrate Soda, 1868, and since.

(²) 2000 lbs. the first 6 years (1852-7).

The seed was sown on March 13th; the earlier crops were cut on August 5th, and carted on August 16th; and the later cut on August 19th, and carted on August 25th. Between cutting and carting there was some cold and showery weather; but notwithstanding the later crops (those not manured with superphosphate) had the benefit of much hotter and drier weather before being carried, than the earlier (which were manured with superphosphate), the latter gave by far the higher weight per bushel; considerably higher indeed than the average. Unlike the wheat, the experimental barley gave, under liberal manuring, very generally more, both corn and straw, than the average; but without

manure, with mineral manure alone, and with ammonia-salts alone, the produce, more especially of corn, was considerably below the average. The crop was, upon the whole, bulky, being heavy in straw; so that even where the produce of corn was more than the average, the proportion of corn to straw was less than the average.

After an unusually wet winter, the soil and subsoil would, doubtless, retain a good deal of moisture at seed-time, and, although March was cold and dry, April was warm and forcing, May was cold and wet, and June also cold; so that the characters of the season were obviously such as would tend to bulk, rather than to seeding tendency. In the case of the barley such was the result, but in that of the wheat the straw was proportionally more deficient than the corn. Again, with barley, there was more than average produce, both corn and straw, with mixed mineral manure and a given amount of nitrogen, whether supplied as ammonia-salts or as nitrate of soda; whereas, with wheat, there was a deficiency of both corn and straw with mineral manure and ammonia-salts, but an excess of both with the same mineral manure and the same amount of nitrogen supplied as nitrate of soda. It will be useful to try and trace the explanation of these differences.

It will be remembered that, in the season of drought of 1868, the experimental wheat-field gave much more, whilst the experimental barley-field gave much less, than average produce. In 1869, however, after a very wet winter, and, for the most part, cold weather at the periods of most active growth, the experimental wheat-field gave generally much less, whilst the barley-field yielded considerably more than the average. Doubtless, the advantage which the wheat had over the barley in the year of drought was due to its having obtained possession of a considerable range of soil before the drought commenced, and being thereby rendered less dependent than the spring-sown barley on the rain actually falling during the periods of active growth. The failure of the wheat as compared with the barley in 1869, after the very wet winter, was probably due, in great measure, to the washing out and loss by drainage of the nitrogen of the ammonia-salts sown in its case in the autumn; whereas, for the barley, the manures were not sown until the spring. A corroboration of this view is the fact that, though there was so considerable a deficiency in the produce of wheat with mixed mineral manure and a given amount of nitrogen supplied in the form of ammonia-salts sown in the autumn, there was no deficiency, but an excess of produce, of that crop, where the same mineral manures and the same amount of nitrogen were supplied,

but the latter in the form of nitrate of soda, and applied no before the winter rains, but in the spring.

In a paper already referred to,* we have pointed out how very serious may be the loss of nitrogen by drainage, when ammonia-salts or nitrates are liberally applied in the autumn, and there is much wet weather during the winter; or even when sown in the spring, if very heavy falls of rain should follow. Not only, however, is the rain of the spring and summer generally less continuous than that of the winter, but, as the season advances, the soil itself is usually in a drier state, there is more evaporation from it, and considerably more also from vegetation, tending to lessen the proportion of the rain passing below the reach of the roots, and carrying with it fertilizing matters. For important data relating to this subject we would refer to a paper by Professor Voelcker.† Some of the results he records we shall quote further on (Section IV. p. 138); but it may be useful to give here a single paragraph from our own paper above referred to.

“Fortunately, some of the most important mineral constituents of soils and manures are, in the case of the heavier soils at any rate, almost wholly retained by them within the range of the roots of our crops. Nitrogen, whether supplied in the form of ammonia-salts or nitrates is, however, much less completely so retained; being, in whichever state supplied, carried off in greater or less quantity in the drainage-water, chiefly in the form of nitrates. According to results obtained independently by Professor Frankland and Professor Voelcker, on the analysis of drainage-water from the experimental wheat-field at Rothamsted, that collected during the winter, from land manured in the autumn by an amount of ammonia-salts supplying 82 lbs. of nitrogen per acre, may contain from 2·5 to 3 parts, or even more, of nitrogen, as nitrates and nitrites, per 100,000 parts of water. Assuming that only 2·5 parts of nitrogen were so carried beyond the reach of roots for every 100,000 parts of water passing downwards, there would still be, for every inch of rain so passing, a loss per acre of between 5 and 6 lbs. of nitrogen, supplied in manure at a cost of not much less than 1s. per lb.”

Now, in December, January, and February, 1868-9, about 10·5 inches of rain fell, being about 4·5 inches more than the average; and although data are at present wanting for anything like an accurate estimate of what proportion of this large amount

* ‘Journal of the Royal Agricultural Society of England,’ vol. vii.—s.s. Part I.

† “On the Productive Powers of soils in relation to the loss of Plant-Food by Drainage.” By Professor Voelcker, Ph.D., F.R.S. (‘Jour. Chem. Soc. Lond.’, June, 1871.)

of rain would pass away by drainage,* it may at any rate be concluded that several inches would do so. It can hardly be wondered at, therefore, that, in the case of the wheat, the plots receiving nitrogen as ammonia-salts in the autumn were much less productive than usual, and also, in a much greater degree than usual, deficient compared with the plot receiving its nitrogen as nitrate of soda applied in the spring.† It is intelligible, too,

* See evidence on this point in the paper in the 'Journal of the Royal Agricultural Society of England,' before referred to. Vol. vii.—s.s. Part I.

† During the early years of the comparative trials, a given amount of nitrogen, applied as ammonia-salts in the autumn, gave more produce of wheat, both corn and straw, than an equal quantity applied in the spring as nitrate of soda; but during the last 12 or 14 years the nitrate of soda, applied in the spring, has given more produce than the ammonia-salts applied in the autumn.

The years in which the nitrate showed specially great superiority over the ammonia-salts, due rather to deficiency of produce by the latter, than to any considerable excess over the average by the former, were 1860, 1867, 1869, and 1871. In 1860 the produce by ammonia-salts was very much less than the average, and by the nitrate slightly under the average, though much above the ammonia-salts; and the records show that there had been an excess of rain in November, December, and January, and again in March, April, May, and June. In 1867 there was a greater deficiency of total produce by the ammonia-salts than in any other year, a small deficiency even by the nitrate, and very great deficiency by the ammonia-salts compared with the nitrate; and there had been a greater or less excess of rain in almost every month from seed-time to harvest, namely, in November, December, January, February, March, April, May, and July. In 1869 there was a considerable deficiency by the ammonia-salts, but less than in 1860 or 1867; and by the nitrate a small excess over its average, and a great excess over the ammonia-salts; and there had been a considerable deficiency of rain in November, but a very considerable excess in December, January, and February, a slight excess in April, and a greater excess in May, but very dry weather afterwards until harvest. Lastly, in 1871, there was a very considerable deficiency by the ammonia-salts, a slight excess by the nitrate, and very great excess by it as compared with the ammonia-salts; there was an excess of rain in December and February, and a great excess in April, June, and July.

There was also considerable excess by the nitrate compared with the ammonia-salts in 1862, in 1866, and in 1868. But in these cases, especially in 1862 and 1868, the result was, for the most part, due to over average produce by the nitrate, and but little, if at all, to under average by the ammonia-salts. Accordingly, in 1861-2, after a considerable deficiency of rain in the three preceding months, there was a considerable excess in November, but again a deficiency in December, January, and February, and then a considerable excess in March, April, May, and June—that is after the nitrate had been applied, but after active vegetation had commenced. Again, in 1868, with a deficiency of rain in each of the four preceding months there was a slight excess in December, considerable excess in January, slight excess in February, March, and April, but very great deficiency afterwards until harvest.

These examples, though differing much from one another in many points, nevertheless sufficiently clearly point to the conclusion that, in the first series of years enumerated, the considerable difference between the amount of produce by the ammonia-salts applied in the autumn, and the nitrate of soda applied in the spring, was due to deficient produce by the former resulting from a washing out of its nitrogen by the winter rains; whilst, in the other instances, it was due to the greater effectiveness of the nitrate under the influence of the conditions of the season after the commencement of active growth, which were widely different in the two cases more specially noticed; giving, in 1862, with a comparatively wet

that the barley, the whole of the manures for which were applied in the spring, should, equally with the wheat-plot which received its nitrogen in the spring, give more than average total produce, and especially an excess of straw.

The very different results obtained with winter-sown and spring-sown crops, in the strikingly contrasted seasons of 1868 and 1869, thus illustrate very instructively the extremely varying effects of some of our most active manures, according to the time of their application, and to the characters of the season. Moreover, with the explanations given, it becomes the more intelligible that, in certain seasons, the accounts of the growing crops should be very conflicting for soils of different characters and in different conditions as to manuring. A consideration of the results obtained in the next season, 1870, which was one of even more prolonged drought than that of 1868, will be confirmatory of the explanations given of the results of that year, and will afford further opportunity for usefully directing attention to the points involved.

Nineteenth Season, 1870.

Until the middle of October the autumn of 1869 was for the most part warm, with a good deal of rain. From that time until the end of the year the weather, though including some rapid fluctuations, some very warm days, and a warm period of more than a week in the middle of December, was otherwise very cold and inclement, and especially wintry towards the end of October; there were numerous gales throughout the quarter; but there was less rain than usual in October, about the average in November, and a considerable excess in December. The falls were heavy and continuous at the end of November, and again in the middle of December; and the drains in the experimental wheat-field ran frequently from November 28th, 1869, to January 1st, 1870. The first three months of 1870 were characterised by frequent alternations of warm and very cold weather—the colder periods being, however, much the longer, and sometimes very severe; snow was very frequent, but the rain-gauge indicated a deficient fall in January, in some localities a deficiency in February, but

and cold spring and early summer, a greater excess of straw, and in 1868, with very hot and dry weather during the most active period of growth, a greater excess of corn.

It will be understood that the above remarks are not supposed to give anything like a complete description of the characters and effects of the seasons referred to, but are only intended to illustrate the difference of effect of a given amount of nitrogen supplied as ammonia-salts in the autumn, and as nitrate of soda in the spring, dependent, in great measure, on the different degree of liability to loss by drainage in the two cases.

a very heavy fall early in the month, and an excess in March. From early in April to near the end of the month the weather was very warm and dry; then followed about a fortnight of cold and cloudy weather, from which time until nearly the end of June it was again very warm, sunny, and dry—the three months together being not only warmer than the average, but very unusually deficient in rain. The day-temperatures especially were high, though the night-temperatures were in April and May low, but in June high. The end of June and the beginning of July were cold and variable, but the remainder—indeed, nearly the whole of July, as well as the first half of August—were very warm. Then, to the end of September, a period of about six weeks, the temperatures were pretty uniformly below the average, though the weather continued fine. Thus, the period of drought, which had commenced with April, continued to nearly the end of August, and even in September there was less than the average fall of rain. The great deficiency of rain throughout five consecutive months was, moreover, accompanied by great dryness of atmosphere—the degree of humidity of the air being in April very unusually low, and in May, June, July, and August, also considerably below the average.

The autumn of 1869, though, as the details show, frequently cold, boisterous, and inclement, was, upon the whole, not unfavourable for getting in the seed. The winter, though changeable, included a great deal of very cold weather. In the early spring both field-work and vegetation were very backward, and at the end of April grass-land was very brown and bare. From the beginning of April until harvest the weather was, with few exceptions, of short duration, warmer than usual, with a great deficiency of rain and a very dry atmosphere.

The combined heat and drought were even more extreme during the months of May, June, and July, 1868, than during the corresponding months in 1870; but in the latter year the deficiency of rain commenced a month earlier, and continued later than in 1868. Hence, the grass crops suffered the more, indeed very excessively, in 1870; and, for a parallel, we must go back as far as 1844. As in the two preceding years (1868 and 1869), the reports of the cereal crops of the country were very variable, but for very opposite reasons in the years of heat and drought, 1868 and 1870, as compared with 1869. In 1870, the year now under consideration, the wheat plant suffered much before the active growing time began—in some cases from wire-worm, and in others from frosts; in not a few instances it was ploughed up and spring-corn sown; whilst, over large areas, the remaining plant was said to be very thin on the ground, and there was very much

more than usual difference in the character of the crops in adjoining fields. Still, the best wheat lands were said to carry, though not a bulky, yet a very good yielding crop, and to give grain of very high weight per bushel. Estimates of the aggregate yield for the most part put it, if not under, at scarcely over an average; but the annual report from Rothamsted (though admitting that the country had probably produced some of the lightest as well as some of the best crops ever known) laid it at rather over average. Barley was also very variable. The seed had for the most part been got in well, and, where sown early and in deep soils, was good; but when sown late, and in light soils, it had suffered very much from the drought. Oats were also generally well got in; but, besides injury from wire-worm, they had suffered from the heat and drought more than either wheat or barley, and gave, upon the whole, a very light crop throughout Midland, Eastern, and Southern districts.

The experimental wheat-field gave, under all conditions of manuring, considerably less than the average produce of straw; but, without manure, and with farmyard-manure, about the average, and with liberal artificial manuring (mineral manure and ammonia-salts or nitrate of soda) considerably more than the average quantity of corn. Under all conditions the weight per bushel was much over the average; in fact, generally, though not uniformly, as high as in any preceding year. The following results were obtained in the experimental barley-field:—

TABLE XX.—Quantity and Quality of Barley on Selected Plots.
Nineteenth Season, 1870.

Plots.	MANURES, PER ACRE.	PRODUCE PER ACRE, &c.					
		Dressed Corn.		Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn to 100 Straw.
		Quantity.	Weight per Bush.				
		Bushels.	lbs.	lbs.	Cwts.	lbs.	
7	14 Tons Farmyard Manure	47½	57·1	2734	19½	4950	123·4
1 O	Unmanured	13½	52·9	751	6½	1489	101·8
4 O	Mixed Mineral Manure ..	18½	55·6	1053	9½	2101	100·5
1 A	200 lbs. Ammonia-salts ..	27½	54·6	1539	12½	2945	109·4
4 A	Mixed Mineral Manure, and 200 lbs. Ammonia-salts ..	38	57·1	2197	18½	4287	105·1
4 A A	Mixed Mineral Manure, and 275 lbs. Nitrate Soda ⁽¹⁾	44½	57·1	2571	18½	4621	125·4
4 C	Mixed Mineral Manure, and 1000 lbs. ⁽²⁾ Rape-cake ..	43½	58·0	2569	20½	4857	112·3

⁽¹⁾ 400 lbs. Ammonia-salts the first 6 years (1852-7), 200 lbs. the next 10 years (1858-67); 275 lbs. Nitrate Soda, 1868, and since.

⁽²⁾ 2000 lbs. the first 6 years (1852-7).

The seed was sown on March 15; the usually earliest plots were cut on July 27, and carted on August 5; and the remainder were cut on August 8, and carted on August 12. With a very unusually deficient rain-fall from the date of sowing until harvest, and also a great deal of hot weather, the amount of total produce (corn and straw together) was, as might be expected, very much below the average; and the deficiency of straw was throughout greater than that of corn. Without manure, and with mineral manure alone, the produce of corn was only two-thirds the average, and that of straw even less, especially without manure. In most other cases the produce of straw was only about two-thirds the average, whilst that of corn ranged from five-sixths of the average to nearly average. As in 1868, the deficiency of corn was much less with farmyard-manure, and with mineral manure and nitrate of soda, than with mineral manure and ammonia-salts. In 1870 it was also considerably less with mineral manure and rape-cake. The proportion of corn to straw was, under all conditions of manuring, very high, and under some higher than in any other year of the twenty. It was the highest, indeed very unusually high, with farmyard-manure, with rape-cake, and with mixed mineral manure and nitrate of soda. The only years approaching 1870 in proportion of corn to straw were 1857 and 1865, both of which had, however, considerably the advantage in actual quantity of corn per acre. The quality of the grain, as indicated by the weight per bushel, was throughout considerably higher than the average, and under some of the most liberal conditions of manuring it was as high as, or higher than, in any other year.

Thus, with a drought of extraordinary severity, extending through the whole period of active growth and ripening, accompanied for the most part with higher temperatures than usual, and a very dry atmosphere, the experimental wheat-field gave considerably less straw, but with high artificial manuring considerably more corn, than the average, and grain of very high quality. The spring-sown barley, on the other hand, gave a crop deficient in both straw and corn; very deficient in straw, and very deficient in corn also with defective manuring, though much less so with high manuring; and, like the wheat, it gave grain of very high quality. The greater power of the winter-sown crop to withstand spring and summer drought and heat, provided the subsoil be moderately retentive, is here again illustrated.

Compared with 1868, which was considerably hotter during May, June, and July, but not deficient in rain in April or August as well as the intermediate months as was 1870, the experimental wheat-field gave, in 1870, very much less straw

than in 1868, but under liberal artificial manuring about, or nearly, as much corn. The experimental barley-field, on the other hand, gave under some conditions of manuring more, but, upon the whole, less straw, though, under high manuring, more corn in 1870 than in 1868. In fact, owing to the greater heat, the soil was probably deprived of its moisture to a greater degree by the shorter drought of 1868 than by the longer one of 1870, and hence the less productiveness of the spring-sown crop in the former than in the latter year.

When speaking of the crop of 1868, attention was called to the fact that the farmyard-manure plot, and the one receiving mixed mineral manure and nitrate of soda, suffered much less from the drought than that receiving mixed mineral manure and ammonia salts. In 1870 the general character of the results was, as already intimated, very similar. Under each of the conditions mentioned, the deficiency of straw was, it is true, considerably greater in 1870 than in 1868; due, doubtless, to the much less rain in April; but the produce of corn was, with farmyard-manure considerably higher than, and with mixed mineral manure and nitrate of soda nearly as high as, in 1868; indeed, with farmyard-manure, it was very nearly average, and with the nitrate, as in 1868, very much higher than by mixed mineral manure and the same amount of nitrogen supplied as ammonia salts—though, as the produce by the ammonia salts was not so defective in 1870 as in 1868, neither was the excess by the nitrate so great as then. There can be little doubt that, the greater porosity of the soil, and the consequently greater power of absorption and retention of moisture near the surface, where the dung was applied, and the greater disintegration and porosity of the subsoil, and the more extended distribution of the manure and of the roots within it, where the nitrate was used, had again enabled the growing crops the better to withstand the heat and drought.

To sum up: The extraordinarily prolonged season of drought of 1870, though yielding, as might be expected, small amounts of total produce (corn and straw together), of both wheat and barley, but especially of the spring-sown crop, was remarkable for giving, of wheat grain even an excess, and of barley grain much less deficiency, the higher the manuring; much less deficiency with farmyard-manure, and with nitrate of soda, than with ammonia-salts; and, with both crops, very high proportion of corn to straw, and very high weight per bushel of corn,

Twentieth Season, 1871.

In October, 1870, the changes of temperature were very frequent, giving, however, about the average for the month; and there was a slight excess of rain. The first 19 days of November were for the most part cold, the remainder warm, but the average for the month was low, and there was a considerable deficiency of rain. There were about 10 days of very warm weather in the middle of December, but the beginning and end of the month were cold; the latter extremely so, with a good deal of snow and cold wind; the average for the month was 5 or 6 degrees below the average for 99 years; and the rain, and melted snow, indicated a considerable excess of fall. January, 1871, with the exception of a few days in the middle of the month, was cold; and at the beginning, and for nearly a fortnight at the end, the weather was extremely severe. From early in February, until the middle of March, the weather was very mild, and thence to the end of the month the temperatures were very variable. There was a full amount of rain (or snow) in January, but a deficiency in both February and March; though the melting of the snows of January, succeeded by frequent rains early in February, caused floods in many parts. April, May, and June were, with the exception of the latter half of April, which was warm with a good deal of south-west wind and rain, unusually cold, with a great deal of east or north wind, or some compound of the two; and there was an excess of rain in April and June, but a deficiency in May; June, especially, being very unseasonably cold and wet. July, excepting about a week after the middle of the month, was cold, with a considerable excess of rain; but, from early in August to about the middle of September, there was a period of 6 weeks of warm and genial weather, from which time, till the end of September, it was again very cold, wet, and stormy. August was not only warm, but there was very little rain, whilst in September there was, towards the end of the month, a great excess of rain. The degree of humidity of the air was high in April and June, rather high in July, rather low in May, very low in August, and low in September.

The autumn of 1870 was thus changeable as to temperature, upon the whole cold, wet during the first half of September, and also of October, but afterwards comparatively dry and favourable for field work. The greater part of the winter was extremely severe, with a good deal of snow, and very cold winds; the remainder was mild and very wet, retarding field work and spring sowing; whilst winter corn was very backward, in many

cases injured, pastures very bare, and vegetables very scarce. The hard winter had, however, killed many insects, and March was favourable for field work and sowing. With the exception of the latter half of April, the remainder of the spring was cold and backward. The rest of the active growing period was, excepting one or two intervals of short duration, cold, bleak, and very wet; hay was much damaged, corn crops were very backward, and in many cases much laid. In the greater part of England, however, August and the early part of September were warm and dry, much aiding the ripening and getting in of the crops; but the latter half of September was cold and wet.

With a very severe winter, a cold spring, more than the first half of the summer also cold, and a great excess of rain in June and July, the reports of the wheat crop of the country were, with few exceptions, unfavourable. The seed had mostly been got in well, but with a winter of intense frosts, and high east winds sweeping the snow which fell into the furrows, hollows, and hedges, much wheat was killed or injured. A good deal was ploughed up, some re-sown in the spring; the heavy soils suffered most, and the crops were much laid in July; but the ripening and harvest periods were more favourable. Still, the crop was estimated at much below the average in quantity, and considerably, though less, below the average in quality. Owing to the drought of the previous summer, and the frosts of the winter, the land was in a very healthy condition for spring-sowing; the weather was favourable in March, and spring crops were generally well got in. Barley was throughout the early portions of the season generally pronounced to promise well. Later, the heavier crops were a good deal laid; but at harvest the aggregate crop was concluded to be considerably over the average in quantity, and, for the most part, of fair, or even of good quality. Oats, on the other hand, were more generally less promising; injury from wire-worm was not unfrequent, and eventually the crop was estimated at under average.

In the experimental wheat-field the produce of both corn and straw was, by farmyard-manure, notably above the average of 28 years; but, without manure, and under nearly all conditions of artificial manuring, it was in a greater degree below the average, and proportionally more deficient in corn than in straw. The exception was the plot with mineral manure and nitrate of soda, which gave more than the average produce of straw, and proportionally less deficiency of corn, than the other artificial manures. The weight per bushel of corn was also considerably below the average in all cases excepting with farmyard manure and the mixture of mineral manure and nitrate of soda. The following results were obtained in the experimental barley field:—

TABLE XXI.—Quantity and Quality of Barley on Selected Plots.
Twentieth Season, 1871.

Plots.	MANURES, PER ACRE.	PRODUCE PER ACRE, &c.					
		Dressed Corn.		Total Corn.	Straw and Chaff.	Total Produce (Corn and Straw).	Corn to 100 Straw.
		Quantity	Weight per Bush.				
7	14 Tons Farmyard Manure	Bushels. 54½	lbs. 56·6	lbs. 3243	Cwts. 37½	lbs. 7401	78·0
1 O	Unmanured	16½	55·0	973	11	2208	78·8
4 O	Mixed Mineral Manure ..	25	55·6	1438	14	3002	92·0
1 A	200 lbs. Ammonia-salts ..	36½	55·6	2129	23½	4712	82·5
4 A	Mixed Mineral Manure, and 200 lbs. Ammonia-salts ..	46½	56·5	2769	32½	6404	76·2
4 A A	Mixed Mineral Manure, and 275 lbs. Nitrate Soda ⁽¹⁾	46	56·3	2683	32½	6333	73·5
4 C	Mixed Mineral Manure, and 1000 lbs. ⁽²⁾ Rape-cake ..	47½	56·4	2809	32	6394	78·4

⁽¹⁾ 400 lbs. Ammonia-salts the first 6 years (1852-7), 200 lbs. the next 10 years (1858-67); 275 lbs. Nitrate Soda, 1868, and since.

⁽²⁾ 2000 lbs. the first 6 years (1852-7).

The seed was sown on March 4; the more forward plots, which this season were only those manured with nitrate of soda and phosphates, and those with rape-cake, were cut on August 11 and 12, and carted on August 16; the remainder, indeed the majority, were cut on August 14 and 15, and carted on August 21. With nearly the whole of the active growing period cold and very wet, the crops of this, the twentieth season in succession of the growth of barley on the same land, were, under nearly all conditions of high manuring, more bulky than usual, but many of them were much laid. The excess of straw, compared with the average, was especially great with farmyard-manure. The proportion of corn to straw was in all cases below the average. But, with much improved weather at the ripening and harvest time, the actual quantity of corn per acre was, under most conditions of high manuring, and especially with farmyard manure, above the average; and the weight per bushel of dressed corn was, under all conditions without exception, above the average.

When speaking of the results obtained in the barley-field in the two years of summer drought, 1868 and 1870, particular attention was called to the fact that the plots manured with farmyard manure, or with nitrate of soda, withstood the drought much better than those manured with ammonia-salts. After the wet and cold spring and summer of 1871, the farmyard manure still gave very high total produce—indeed as high as in any year of the twenty excepting 1864; as heavy a weight of straw as in any year excepting 1864 and 1854; and as much corn as in any year

excepting 1864 and 1863. But the nitrate-of-soda plots, though giving more corn, and considerably more straw, than in either of the years of drought, did not in this wet and cold season show the same superiority over the plots manured with ammonia-salts that they did in either 1868 or 1870. The nitrated plot—the results of which are quoted in the Tables (4 A A.)—being one of the ripest in the field, suffered, it is true, considerably by the depredations of birds; but, independently of this, there is evidence enough that the nitrate did not show the same superiority over the ammonia-salts in the cold and wet as in the hot and dry season. Something may be due to the greater exhaustion of the nitrated plots in the preceding years of drought; but something is, doubtless, also due to more loss by drainage of the nitrogen of the spring-sown nitrate, than of that of the also spring-sown ammonia-salts, during the wet summer of 1871.

In connection with the fact, and the explanation, of the comparatively defective result with the nitrate in a wet summer when applied to barley, the very opposite result with wheat is of considerable interest. Thus, as already mentioned, there was, in the experimental wheat-field, much less deficiency of corn, and even an excess of straw, by the nitrate, as compared with the ammonia-salts. The explanation of the difference of effect with the two crops would seem to be, that whilst for the wheat the nitrate was not sown until the spring, the ammonia-salts had been sown in the previous autumn, and were subject to a considerable loss by drainage during several extremely wet periods of the winter, when there was no growth, and before the nitrate was sown. It will be remembered that a similar result was obtained with wheat after the wet winter of 1868-9; and also in other years, as referred to in the foot-note at p. 62.

Finally, it will be observed that the results obtained in the experimental fields are in the main in accord with the reports of the crops of the country at large, in showing a considerably deficient wheat-crop, and a barley-crop above the average both in quantity and quality, though the twentieth in succession on the same land.

Comparison of the Produce of Barley in the least, and in the most, productive Seasons of the Twenty.

The foregoing records of the characters of the seasons, and of the produce of barley in each individual year of the twenty, with the comments made upon them, very forcibly illustrate the diversity between one season and another, and how very varied is the final result, dependent on the mutual adaptations of heat,

TABLE XXII.—Quantity and Quality of Barley on Selected Plots, in the least, and in the most, productive Season of the twenty.

Plots.	MANURES, PER ACRE.	Least Productive Season, 1856.	Most Productive Season, 1854.	Difference over (or under—) 1856.
--------	--------------------	--------------------------------	-------------------------------	-----------------------------------

Weight per Bushel of Dressed Corn.

		lbs.	lbs.	lbs.
7	14 Tons Farmyard Manure	47.1	53.9	6.8
1 O	Unmanured	49.1	53.6	4.5
4 O	Mixed Mineral Manure	47.0	54.0	7.0
1 A	200 lbs. Ammonia-salts	48.5	53.6	5.1
4 A	Mixed Min. Man., and 200 lbs. Ammonia-salts	46.4	54.3	7.9
4 A A	Mixed Min. Man., and 400 lbs. Ammonia-salts	45.4	52.1	6.7
4 C	Mixed Min. Man., and 2000 lbs. Rape-cake ..	46.3	52.8	6.5

Total Corn per Acre, reckoned at 52 lbs. per Bushel.

		Bushels.	Bushels.	Bushels.
7	14 Tons Farmyard Manure	317	601	284
1 O	Unmanured	151	372	221
4 O	Mixed Mineral Manure	191	451	260
1 A	200 lbs. Ammonia-salts	271	531	251
4 A	Mixed Min. Man., and 200 lbs. Ammonia-salts	301	66	351
4 A A	Mixed Min. Man., and 400 lbs. Ammonia-salts	361	68	311
4 C	Mixed Min. Man., and 2000 lbs. Rape-cake ..	351	651	301

Straw (and Chaff), per Acre.

		Cwts.	Cwts.	Cwts.
7	14 Tons Farmyard Manure	191	371	171
1 O	Unmanured	81	211	13
4 O	Mixed Mineral Manure	91	231	131
1 A	200 lbs. Ammonia-salts	171	301	131
4 A	Mixed Min. Man., and 200 lbs. Ammonia-salts	211	401	191
4 A A	Mixed Min. Man., and 400 lbs. Ammonia-salts	33	49	16
4 C	Mixed Min. Man., and 2000 lbs. Rape-cake ..	301	421	111

Total Produce (Corn and Straw), per Acre.

		lbs.	lbs.	lbs.
7	14 Tons Farmyard Manure	3868	7298	3432
1 O	Unmanured	1797	4405	2608
4 O	Mixed Mineral Manure	2075	4969	2894
1 A	200 lbs. Ammonia-salts	3347	6155	2808
4 A	Mixed Min. Man., and 200 lbs. Ammonia-salts	3981	7958	3977
4 A A	Mixed Min. Man., and 400 lbs. Ammonia-salts	5582	9026	3444
4 C	Mixed Min. Man., and 2000 lbs. Rape-cake ..	5257	8125	2868

Corn to 100 Straw.

		lbs.	lbs.	lbs.
7	14 Tons Farmyard Manure	74.9	75.0	0.1
1 O	Unmanured	82.4	80.4	-2.0
4 O	Mixed Mineral Manure	96.3	91.5	-4.8
1 A	200 lbs. Ammonia-salts	74.8	81.5	6.7
4 A	Mixed Min. Man., and 200 lbs. Ammonia-salts	67.1	75.7	8.6
4 A A	Mixed Min. Man., and 400 lbs. Ammonia-salts	51.0	64.5	13.5
4 C	Mixed Min. Man., and 2000 lbs. Rape-cake ..	53.9	72.4	18.5

moisture, and stage of growth of the crops. In no two years has one and the same manure yielded precisely the same result both as to the quantity and the quality of its produce. Nor have the seasons which have been more or less favourable than the average for one description of manure, been equally favourable or unfavourable for other descriptions.

Referring to the previous discussion, and to the materials brought together in the Appendix-Tables (pp. 179—201), for any more detailed consideration of the subject, it must suffice here, by way of illustration and summary, to call special attention to the produce yielded by the same description and quantity of manure in the least, and in the most, productive season of the twenty.

Table XXII. (see opposite page) shows, side by side, the quantity and quality of the produce obtained in 1854, which was upon the whole the most, and in 1856, which was upon the whole the least, productive of the twenty seasons; also the difference between the two. For the purposes of this illustration, the same selection of plots has been made as in the foregoing consideration of the produce of each individual season. It is true that one or other of the descriptions of manure specified may have given more corn, or a higher weight per bushel, or more straw, in some other season than it did in 1854, or a worse result, on some point or other, than in 1856. But, looking chiefly to the results obtained under the best conditions of manuring, and the general characters of the produce, there can be no doubt that the seasons selected do, upon the whole, represent, respectively, the least, and the most, productive of the series.

In the first place, the weight per bushel of dressed corn was from $4\frac{1}{2}$ lbs. to nearly 8 lbs. less in the bad than in the good year, or from about $8\frac{1}{2}$ to nearly 15 per cent. less in the one case than in the other. Under almost every condition of manuring, 1856 was the worst season, so far as this point is concerned; but several other seasons gave higher weight per bushel than 1854.

It is obvious that, with a difference of from $8\frac{1}{2}$ to 15 per cent. in the weight of the bushel, a comparison of the actual number of bushels of dressed corn in the two seasons would much underrate the difference in the amount of produce, greatly to the disadvantage of the most productive one. Accordingly, the quantity of *total corn*, per acre, has, in each case, been calculated into bushels of the assumed uniform weight of 52 lbs. per bushel; and the results of this calculation are given in the second division of the Table.

There was, *without manure*, in the bad season about $15\frac{1}{2}$, in the good season $37\frac{1}{4}$ bushels of corn, or a difference of rather

more than 22 bushels between the two; and also a difference in the quantity of straw amounting to 13 cwt. per acre.

With *farmyard manure*, the unfavourable season of 1856 gave scarcely 32 bushels, whilst 1854 gave rather over 60 bushels, or a difference of $28\frac{1}{2}$ bushels of corn; and there was also a difference of $17\frac{1}{2}$ cwt. of straw.

Lastly, the three most productive artificial manures gave, respectively, in 1856, $30\frac{1}{2}$, $36\frac{1}{2}$, and $35\frac{3}{8}$ bushels of corn, and in 1854, 66, 68, and $65\frac{5}{8}$ bushels, or a difference in favour of the good year of $35\frac{1}{2}$, $31\frac{1}{2}$, and $30\frac{1}{2}$ bushels of corn, besides $19\frac{1}{2}$, 16, and $11\frac{5}{8}$ cwt. of straw.

Thus, with one and the same expenditure for manure, there was a difference in the quantity of produce obtained in the two seasons of from 30 to 35 bushels of corn, and in one case of nearly a ton of straw, or not much less than would represent the average barley-crop of many localities.

It is worthy of remark that, whilst the season of 1856 was far worse than that of 1853 as regards both the quantity and the quality of the barley-crop, 1853 was, for the experimental wheat (which that year could not be sown until the spring), in every particular worse than 1856. Again, whilst 1854 was a decidedly more productive barley-year than 1863, yielding under almost every condition of manuring not only more corn, but considerably more straw—in other words, a greater quantity of total produce, indicating greater luxuriance—1863 was, on the other hand, a considerably more productive wheat-year than 1854, and especially so in corn. Both years were, however, remarkable for very large produce of both corn and straw, of both wheat and barley.

The years next in order of productiveness, so far as the barley crop is concerned, were 1857 and 1864, which were very good wheat years also. But neither 1863, nor either of the two years last mentioned, yielded anything like the same amount of total crop, corn and straw together, as 1854. The years next in order to 1856 in point of badness of barley-crop were 1859, 1860, 1868, and 1870; the deficiency in the two last-mentioned years being due to summer heat and drought, but in the other two seasons to very opposite conditions.

The question arises—to what characters of season are the extreme differences of produce which have been traced to be attributed? Referring to the details already given respecting each individual season, so far as the other years above enumerated are concerned, it must suffice here to recall attention to the distinctive characters of the season of 1856 yielding the worst, and of 1854 yielding the best, barley-crop of the twenty years.

The very unusually productive season of 1854 had been

preceded by a very severe winter; March and April were upon the whole warmer than usual, but May, June, July, and August were pretty uniformly below the average temperature; whilst in March, April, June, and July there was a very considerable deficiency of rain, though more than the average number of rainy days. In May, however, there was about double the usual amount of rain, and an unusually large number of rainy days. In August, again, there was a full amount of rain, which, however, fell for the most part in heavy showers, and the month was upon the whole favourable for ripening and harvest.

Thus, the season of 1854 was characterised by prevailing low rather than high temperatures, an abundance of rain at the period of early active growth (doubtless favouring root development), and again before harvest, but otherwise by dryness as well as coolness. It would seem, therefore, that the large produce was due to a sufficiency of moisture within the soil when most wanted, with, at other times, comparatively dry and temperate atmospheric conditions, resulting in a continuity of unchecked growth, rather than in very active luxuriance at intervals.

Compared, or rather contrasted, with the above climatic conditions, those of the extremely unfavourable season of 1856 were as follows:—

There had been some severe weather in the early part of the winter, but the later and greater part was upon the whole mild. March, April, and especially May, were colder than the average, whilst June, July, and August, though showing average day-temperatures fully as high as usual, were very changeable, and in June and July the nights were cold. In each of the months of January, February, March, April, May, June, and July, there was considerably more rain than in the corresponding months of 1854—in all nearly 6 inches more; whilst, in April there was an excess over the average, in May more than double the average, and in August again an excess.

The season of 1856 was, therefore, characterised by a great excess of rain during the early periods of growth; considerably more than in 1854, and there was, besides, considerably more than in that year, both before and after that period. There were also, almost throughout, great fluctuations, and high ranges, of temperature. In other words, the season was very wet, with marked alternations of heat and cold, whilst it was, for the period of the year, the coldest during the time of the greatest excess of rain. Finally, there were heavy rains, with considerable fluctuations of temperature, about the ripening and harvest period. The very bad result in this season would seem to be due, therefore, to an excess of rain, with, at the same time, great

alternations of temperature, during the most active periods of growth, entirely preventing continuity of progress; whilst the unhealthy plant thus produced was subjected to unfavourable maturing conditions.

The above description of the climatic conditions of the two seasons, as collated from meteorological records, will probably strike the reader as not showing so great a contrast as would be expected between the season of the greatest, and that of the least, productiveness of the twenty. Certainly 1854 was not marked by individual periods of more than ordinarily active luxuriance; the circumstances were rather those of steady and unbroken accumulation, followed by favourable maturing conditions. The extremely productive season of 1863 showed in this respect similar characteristics. It should be remembered, indeed, that both wheat and barley will flourish under very temperate conditions. Again, the record of the climatic circumstances under which the extremely bad crop of 1856 was produced, shows some points in respect to which, considered by themselves, it might be judged to have been more favourable for luxuriance than 1854. It is only when the fluctuations of temperature, the continuity of the wetness, and the adaptations of heat and moisture to stage of growth, are borne in mind, that the result becomes intelligible.

These two instances, so strikingly contrasted in their results, forcibly illustrate the necessity, not only of very careful and detailed study of the meteorological registry, but also of due consideration of its indications in their bearings upon the coincident stage and tendency of growth of the plant, if we would attain any really clear conception of the connection between the ever fluctuating characters of season, and the equally fluctuating characters of growth and produce.

Comparison of the average Annual Produce of Barley over the first 10, the second 10, and the total period of 20 years.

There is still another point in connection with the influence of season upon the crop, which should be considered before treating more exclusively of the effects of the different manures. Thus, before attempting to compare the effects of different manures, used year after year on the same plot, it is obviously necessary to form a judgment whether the earlier or the later seasons of the series were, in themselves, the most favourable, so as to distinguish as far as possible between the results due, on the one hand to more or less favourable seasons, and on the other to the direct action of the manures, in maintaining a suitable balance of the required constituents in the soil, or in inducing exhaustion, or accumulation, as the case may be.

TABLE XXIII.—Average Annual quantity and quality of Barley, on Selected Plots, over the first 10 years, the second 10 years, and the Total Period of 20 years.

Plots.	MANURES, PER ACRE.	AVERAGE ANNUAL PRODUCE, &c.			Second 10 Years over (or under —) First 10.
		First 10 Years, 1852-'61.	Second 10 Years, 1862-'71.	Total Period 20 Years, 1852-'71.	

Weight per Bushel of Dressed Corn.

		lbs.	lbs.	lbs.	Per Cent.
7	14 Tons Farmyard Manure	52·6	56·0	54·3	6·5
1 O	Unmanured	51·6	53·1	52·3	2·9
4 O	Mixed Mineral Manure	52·3	54·6	53·4	4·4
1 A	200 lbs. Ammonia-salts	51·2	53·0	52·1	3·5
4 A	200 lbs. Amm.-salts, Mixed Min. Man.	52·2	55·7	54·0	6·7

Total Corn per Acre, reckoned at 52 lbs. per Bushel.

		Bushels.	Bushels.	Bushels.	Per Cent.
7	14 Tons Farmyard Manure	48½	57½	53½	17·6
1 O	Unmanured	24½	18½	21½	—23·4
4 O	Mixed Mineral Manure	32½	26½	29½	—16·0
1 A	200 lbs. Ammonia-salts	36½	34	35½	—7·5
4 A	200 lbs. Amm.-salts, Mixed Min. Man.	49½	51½	50½	3·0

Straw (and Chaff), per Acre.

		Cwts.	Cwts.	Cwts.	Per Cent.
7	14 Tons Farmyard Manure	26½	29½	28½	12·2
1 O	Unmanured	13½	10½	11½	—23·4
4 O	Mixed Mineral Manure	16½	12½	14½	—21·7
1 A	200 lbs. Ammonia-salts	19½	17½	18½	—12·0
4 A	200 lbs. Amm.-salts, Mixed Min. Man.	28½	28	28½	—3·0

Total Produce (Corn and Straw), per Acre.

		lbs.	lbs.	lbs.	Per Cent.
7	14 Tons Farmyard Manure	5525	6342	5933	14·8
1 O	Unmanured	2782	2126	2454	—23·6
4 O	Mixed Mineral Manure	3517	2807	3162	—20·2
1 A	200 lbs. Ammonia-salts	4119	3719	3919	—9·7
4 A	200 lbs. Amm.-salts, Mixed Min. Man.	5827	5808	5817	—0·3

Corn to 100 Straw.

		lbs.	lbs.	lbs.	Per Cent.
7	14 Tons Farmyard Manure	85·6	91·3	88·5	6·7
1 O	Unmanured	85·9	87·3	86·6	1·6
4 O	Mixed Mineral Manure	95·1	97·7	96·4	2·7
1 A	200 lbs. Ammonia-salts	86·4	91·9	89·2	6·4
4 A	200 lbs. Amm.-salts, Mixed Min. Man.	79·9	86·4	83·2	8·1

In Table XXIII. (p. 77) there is given the average produce over the first ten, the second ten, and the total period of twenty years, by very different descriptions of manure, and a comparison of the results will illustrate the point in question. The plots selected are 5 out of the 7 quoted in the preceding Tables, namely—that manured with farmyard manure every year; the continuously unmanured plot; the one with mixed mineral manure alone every year; that with 200 lbs. ammonia-salts alone every year; and that with both mixed mineral manure and 200 lbs. ammonia-salts every year. It is obvious that these five plots supply very various, and very opposite soil-conditions, so that the comparative effects of the seasons on each must have considerable significance.

In the first place, there is, with each of the five very opposite conditions of manuring, a considerably higher average weight per bushel of dressed corn over the second, than over the first ten years of the twenty; and the superiority is the greatest with the highest manuring and the heaviest crops—namely, with farmyard manure, and with ammonia-salts and mixed mineral manure together. The proportion of corn to straw is also the higher over the last ten years, and the higher with the heavier crops. Further evidence that the later years were in the main more favourable than the earlier, at least for the production and maturation of grain, is to be found in the fact that there was also a less proportion of offal corn during the second half of the total period.

With a considerable difference in the weight per bushel of the dressed corn, it is obvious that the comparative productiveness of the two periods will not be accurately represented by the actual number of bushels of dressed corn in each case. Accordingly, as before, the quantity of *total corn* has been calculated into assumed bushels of the uniform weight of 52 lbs. These results show, without manure, with mineral manure alone, and with ammonia-salts alone—that is, with defective soil-conditions, a considerable deficiency of corn over the second half of the period; the greater the more defective the manuring, and the greater the relative deficiency of nitrogen in the soil; for the falling off is considerably more marked with mineral manure alone, than with ammonia-salts alone. Under the same three soil-conditions there is as great, or even a greater deficiency of straw, and consequently of total produce also, during the later years.

With farmyard manure, on the other hand, the annual use of which has resulted in a very great accumulation within the soil, not only of nitrogen, but probably of every mineral constituent also, there has been a considerable excess of produce of both corn and straw, but especially of corn, over the second as compared with the first ten years.

With the ammonia-salts and mixed mineral manure together,

by which also the soil has become much richer in most mineral constituents, and at any rate less exhausted if not richer in nitrogen than without manure or with mineral manure alone, there is again a slight increase of corn, but a slight deficiency of straw, over the later years.

The general conclusion from the above results, as well as from others, not here specially referred to, is, that the earlier years of the twenty were, on the average, as favourable, if not more favourable, for quantity of total produce—that is for luxuriance—than the later; but that the later seasons were much more favourable for tendency to seed-forming, and also for the maturation of the grain.

Bearing in mind this conclusion as to the progressive or retrogressive characters of the seasons themselves, we shall be in a position the better to judge of the effects of the different manures when used year after year, for twenty years in succession, on the same land.

SECTION II.—AVERAGE ANNUAL PRODUCE BY EACH DESCRIPTION OF MANURE EMPLOYED.

In this section the object will be to consider more exclusively than hitherto the effects of different manures on the barley-crop; to ascertain what conditions of manuring are the best adapted for the crop in the soil in question; to determine in what constituent, or class of constituents, the soil soonest shows signs of exhaustion by its growth; and to compare the characters of barley with those of wheat in these respects. To this end attention will chiefly be confined to the average results obtained by each manure over a series of years, so as to exclude, as far as possible, the influence of variations of season, the full consideration of which already has so clearly indicated, and so greatly limited, the necessary reference to it here.

With regard to the soil, as already stated, the experimental barley-field immediately adjoins the experimental wheat-field. The soil of both may be described as—"a somewhat heavy loam, with a subsoil of raw yellowish red clay, but resting in its turn upon chalk, which provides good natural drainage." Lastly, the wheat-field is artificially pipe-drained, but the barley-field is not.

The particulars of the manuring, and of the average annual produce, and increase, by manure, on each plot, over the twenty years, are given at one view in the folding Table (XXIV.) facing the next page. The full details will be found in the Appendix Tables (pp. 179-201); and such abstracts as may be needed for the illustration of individual points will be given as we proceed.

Average Annual Produce without Manure.

From the commencement, two plots, at some distance from one another, have been left unmanured; and a third has received, every year, a dressing of ashes (burnt soil and turf), at the rate of 20 bushels per acre per annum. This is much more than the quantity of the same description of ashes mixed with the various artificial manures to aid their even distribution over the land. The experiment was arranged to meet the cavil of Baron Liebig, that inasmuch as we had mixed "ashes" with our manures, we could not form any judgment as to the effects of the latter; and that doubtless part of the effect we attributed to them was due to the "ashes" also employed.

Table XXV. (see page 81) gives the average annual produce on these three practically unmanured plots, over the first ten, the second ten, and the total period of twenty years.

Looking first to the quality of the produce, the average weight per bushel of dressed corn is, on all three plots, considerably higher, and the proportion of corn to straw is either higher, or but little lower, over the last than over the first 10 years.

This result is doubtless due, in great measure, to the character of the seasons; but the fact may be taken as at any rate sufficient evidence that there was no deterioration in the character or health of the plant, from growing the same crop year after year on the same land.

The two unmanured plots, at opposite sides of the field, show an average annual difference, over 20 years, of 2 bushels of corn and $\frac{1}{2}$ cwt. of straw, but considerably less over the last 10, than over the first 10 years. This indicates probably, that the result is, in part, at any rate, due to a difference of condition from previous manuring and cropping, which is becoming gradually reduced, and so the plots the more equalised. It is a question, however, whether the staple may not be rather better on Plot 6-1 than on Plot 1-O.

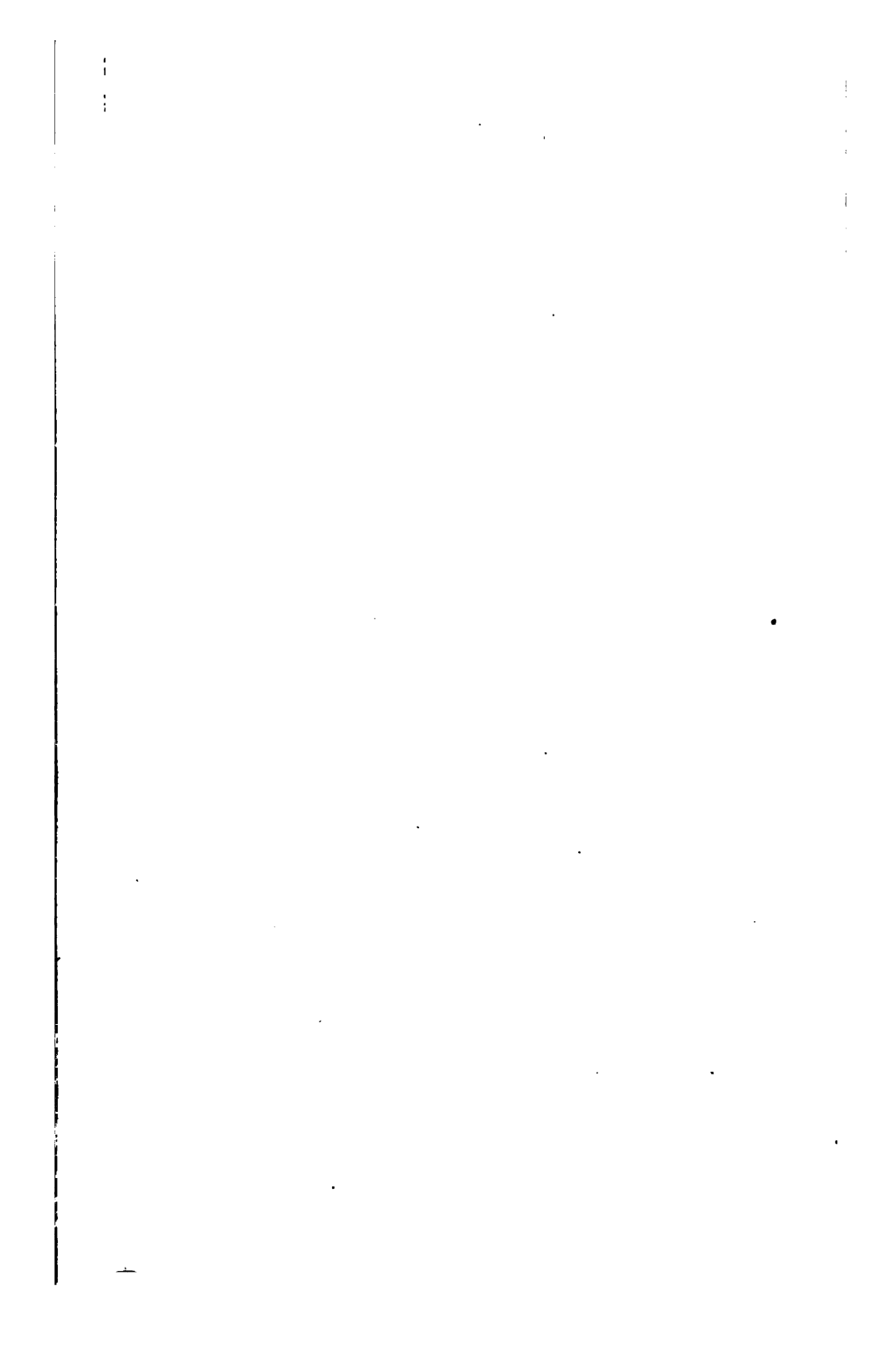
On the other hand, the average produce on Plot 6-2, receiving annually 20 bushels of soil and turf ashes per acre, is only precisely the same in corn, and even rather less in straw, than on the immediately adjoining plot (6-1), which is entirely unmanured. Over the first 10 years, indeed, the ashed plot gave rather less, both corn and straw, than the entirely unmanured one, though rather more of both over the second 10 years. Possibly, therefore, under the exhausting process of growing the crop year after year on the same land, the small amount of manurial matters supplied in the ashes may eventually—that is after, so to speak, all the previously acquired *condition* is worked out of the soil

ON THE SARE. HOOS FIE

—Average Pro

en Mineral and 1 AAS, 2 C, over 2 O;

(unless otherwise sta red.	SEED CORN.		PRODUCE.		PLOTS.
	Over corresponding Mineral Manures.	Over corresponding Unman Mineral Manures.			
ls.	Busbels.	lbs	lbs.		
.. .. .	..	..	..	1 O.	
.. .. .	..	25	..	2 O.	
.. .. .	..	8	..	3 O.	
.. .. .	..	36	..	4 O.	
.. .. .	..	65	..	1 A.	
.. .. .	21½	147	2829	2 A.	
100 lbs. Sulphate	12½	80	1676	3 A.	
100 lbs. Sulphate	18½	144	2655	4 A.	
.. .. .	..	90	..	1 AA.	} (C)
.. .. .	23½	160	3286	2 AA.	
.. .. .	15	94	2167	3 AA.	
.. .. .	22½	162	3281	4 AA.	
.. .. .	..	110	..	1 AAS.	} (C)
.. .. .	22½	178	3138	2 AAS.	
.. .. .	20½	143	2630	3 AAS.	
.. .. .	22½	189	3249	4 AAS.	
.. .. .	..	138	..	1 O.	} (C)
.. .. .	21½	147	2913	2 C.	
.. .. .	21½	130	2886	3 C.	
.. .. .	19½	151	2840	4 C.	
.. .. .	..	95	..	1 N.	} (C)
.. .. .	..	117	..	2 N.	
.. .. .	..	121	..	M.	
.. .. .	..	128	..	5 O.	
.. .. .	21½	1318	2962	5 A.	
.. .. .	..	..	..	1)6	
.. .. .	..	58	..	2)6	
.. .. .	20½	158	2771	7	



—maintain the yield at a slightly higher point than it will reach on the absolutely unmanured land.

TABLE XXV.—Average Annual Produce of Barley without Manure, and with Ashes (burnt soil and turf.)

Plots.		AVERAGE ANNUAL PRODUCE.			Second 10 Years over (or under—) First 10.
		First 10 Years, 1852-'61.	Second 10 Years, 1862-'71.	Total Period, 20 Years, 1852-'71.	
Dressed Corn, per Acre—Bushels.					
1 O	Unmanured continuously	22½	17½	20	Per Cent. —21·8
6 1	Unmanured continuously (duplicate)	25	18½	22	—24·5
6 2	20 Bushels ashes	23½	20	21½	—16·2
Total Corn, per Acre—lbs.					
1 O	Unmanured continuously	1281	985	1133	—23·1
6 1	Unmanured continuously (duplicate)	1414	1070	1242	—24·3
6 2	20 Bushels ashes	1352	1138	1245	—15·8
Straw (and Chaff), per Acre—Cwts.					
1 O	Unmanured continuously	13½	10½	11½	—23·4
6 1	Unmanured continuously (duplicate)	14	10½	12½	—23·2
6 2	20 Bushels ashes	13	11½	12½	—13·5
Total Produce (Corn, Straw, and Chaff), per Acre—lbs.					
1 O	Unmanured continuously	2782	2126	2454	—23·6
6 1	Unmanured continuously (duplicate)	2987	2273	2630	—23·9
6 2	20 Bushels ashes	2814	2391	2603	—15·0
Weight per Bushel of Dressed Corn—lbs.					
1 O	Unmanured continuously	51·6	53·1	52·3	2·9
6 1	Unmanured continuously (duplicate)	51·5	53·5	52·5	3·9
6 2	20 Bushels ashes	51·6	53·6	52·6	3·9
Corn to 100 Straw.					
1 O	Unmanured continuously	85·9	87·3	86·6	1·6
6 1	Unmanured continuously (duplicate)	89·8	89·4	89·6	—0·4
6 2	20 Bushels ashes	92·0	90·9	91·4	—1·2

At any rate, the fact that the plot manured with ashes has,

over 20 years, not given any more produce than the immediately adjoining unmanured plot, is a sufficient answer to the objection that the admixture of a much smaller quantity of the same description of ashes with the artificial manures used on the other plots, in any way vitiates the results, or obscures the proper interpretation of them.

The average annual produce of barley on the land in question, without manure, may be taken at about 21 bushels of grain, and 12 cwt. of straw.

It will be of interest to compare the produce of barley without manure with that of wheat in the immediately adjoining field. Table XXVI. (see next page) illustrates the point; and for the sake of easier comparison, the produce of both crops is given in pounds. For wheat the average annual produce is given—for the whole 28 years of the experiments; for the first 20 years, which will, perhaps, best compare with the barley, so far as condition of land at the commencement of the series is concerned; and for the last 20 years, which comprise the same period as that of the barley results, and will, hence, compare best so far as any influence of season is concerned, but which succeeds 8 years of the growth of the crop without manure. For the barley, the mean produce of the two unmanured plots (1-O and 6-1) is given.

It is seen that, over a period of 20 years without manure, the barley has yielded a greater weight of corn, but less of straw, per acre, per annum, than the wheat. This is the case, whether the produce of wheat be averaged over the whole 28, the first 20, or the last 20 years. The average weight of total produce (corn and straw together) is, however, much more nearly the same for both crops. It is almost identical when the comparison is made with the wheat averaged over the whole 28 years; it is in favour of the wheat when the first 20 years of each crop is taken, and in an almost exactly equal degree in favour of the barley when both crops are taken over the same period, namely, the 20 years—1852-'71, which, in the case of the wheat, succeeded the removal of eight previous unmanured crops, but in that of the barley were the first 20 years of its continuous growth.

Prior to the commencement of the experiments the previous cropping had been as under:—

Wheat-Field.

Turnips (dunged).

Barley.

Peas.

Wheat.

Oats.

Barley-Field.

Turnips (dung and super-phosphate) carted off.

Barley.

Clover.

Wheat.

Barley (sulphate ammonia).

TABLE XXVI.—Average Annual Produce of Wheat, and of Barley, without Manure.

	AVERAGE ANNUAL PRODUCE, &c.				BARLEY MORE (OR LESS—) THAN WHEAT.		
	First Half of Period.	Second Half of Period.	Total Period.	Second Period over (or under—) First Period.	First Half of Period.	Second Half of Period.	Total Period.
Total Corn, per Acre.							
Wheat:—	lbs.	lbs.	lbs.	Per Cent.	lbs.	lbs.	lbs.
28 years, 1844–1871	1053	891	972	–15·4	295	137	216
20 years, 1844–1863	1018	1035	1026	1·7	330	– 7	162
20 years, 1852–1871	944	881	913	– 6·7	404	147	275
Barley:—							
20 years, 1852–1871	1348	1028	1188	–23·7			
Straw (and Chaff), per Acre.							
Wheat:—							
28 years, 1844–1871	1713	1355	1534	–20·9	–176	–183	–180
20 years, 1844–1863	1693	1693	1693	..	–156	–521	–339
20 years, 1852–1871	1663	1241	1451	–25·4	–126	– 69	– 97
Barley:—							
20 years, 1852–1871	1537	1172	1354	–23·7			
Total Produce (Corn, Straw, and Chaff), per Acre.							
Wheat:—							
28 years, 1844–1871	2766	2246	2506	–18·8	119	– 46	36
20 years, 1844–1863	2711	2728	2719	0·6	174	–528	–177
20 years, 1852–1871	2607	2122	2364	–18·6	278	78	178
Barley:—							
20 years, 1852–1871	2885	2200	2542	–23·7			

It is possible, therefore, that there would be rather more *nitrogenous condition* to work out of the barley than out of the wheat land. Consistently with this, the barley gives much more excess of corn, and much less deficiency of straw, compared with the wheat in the earlier years. It also shows much more rapid decline in total produce than the wheat. The evidence leads to the conclusion, therefore, that the wheat will eventually maintain a somewhat higher total produce than the barley. This is what would be expected with the autumn-sown crop, with its longer period for root-development, and consequent possession of a greater range of soil for the collection of food.

It has already been shown that what may be termed, in an

agricultural sense, corresponding crops of wheat and barley require very nearly identical amounts of the different constituents to be available within the soil. These results show, experimentally, how nearly equal are the amounts of *gross produce* of the two crops, which a soil in a given condition will yield; and it seems probable that the only difference will be that which is due to varying adaptation of season, and to the greater or less root-range of the one crop or the other.

Average Annual Produce by Farmyard Manure.

Table XXVII. shows the average annual produce of barley and the increase over the mean produce without manure, by an annual dressing of 14 tons of farmyard manure per acre.

TABLE XXVII.—Average Annual Produce, and Increase of Barley by Farmyard Manure (Plot 7.)

	AVERAGE ANNUAL PRODUCE, &c.				INCREASE OVER UNMANURED (Plot 7.)	
	First 10 Years, 1852-'61.	Second 10 Years, 1862-'71.	Total Period, 20 Years, 1852-'71.	Second 10 Years over (or under —) First 10 Years.	First 10 Years, 1852-'61.	Second 10 Years, 1862-'71.
Dressed Corn per acre bushels	45	51½	48½	Per Cent. 14·4	21½	28
Total Corn per acre lbs.	2541	2995	2768	17·9	1193	1867
Straw (and Chaff) per acre . . . cwts.	96½	29½	28½	12·2	12½	27
Total Produce (Corn, Straw, &c.) per acre lbs.	5525	6342	5933	14·8	2640	444
Weight per Bushel of Dressed Corn lbs.	52·6	56·0	54·3	6·5	1·0	2·7
Corn to 100 Straw	85·6	91·8	88·5	6·7	-2·3	3·1

Unlike the produce without manure, that by farmyard manure was, in every particular of quantity, as well as quality, considerably higher over the second than over the first 10 years. Taking the average of the first 10 years, the produce of corn was exceeded by several, and that of straw by more, of the artificial manures; but, over the second 10 years, it was in no case exceeded in average amount of corn, and in only one case in amount of straw. Averaged over the whole period of 20 years, however, several of the mixtures of mineral and nitrogenous manure approached, and some even surpassed, it in produce of corn, more did so in straw, and several in total produce (corn and straw together).

The individual years in which the dunged plot, more or less, exceeded all others, were—in produce of corn, 1859, 1862, 1864, 1865, 1866, 1867, and 1871; in produce of straw, 1862 and

1866 ; and in total produce, 1859, 1862, 1865, 1866, and 1871. For information as to the characters of season, under the influence of which these results were obtained, we must refer to the description of the respective seasons in Section 1.

Whilst the unmanured land gave an average annual produce of only 21 bushels of dressed corn, and about 12 cwts. of straw, the farmyard manure gave $48\frac{1}{2}$ bushels of dressed corn, and $28\frac{1}{2}$ cwts. of straw ; or an average increase over the mean unmanured of $27\frac{1}{2}$ bushels of corn, and $16\frac{1}{8}$ cwts. of straw.

During the 20 years, 280 tons of dung, containing from 80 to 90 tons of dry solid matter, have been applied per acre. But the produce has only amounted to about $24\frac{3}{4}$ tons of corn, and $28\frac{1}{4}$ tons of straw, or in all to only 53 tons ; and the increase, over the produce without manure, has only been about $14\frac{1}{8}$ tons of corn, and $16\frac{1}{8}$ tons of straw—in all $30\frac{1}{4}$ tons of total increase ; which certainly would contain less than one-third as much dry solid matter as was supplied in the dung. The manure would, in fact, supply to the soil very much more of carbon, of nitrogen, of phosphoric acid, of potass, of lime, of magnesia—indeed, probably of every constituent, than the total produce contained ; and, of course, a still greater excess over the amounts taken off in the *increase* of produce.

It is evident that there must be a very great accumulation of constituents in the soil of the dunged plot. Of nitrogen, for example, from 3 to 4 times as much has been applied as to any of the artificially manured plots ; and, judging from the determinations of nitrogen in the soil of the dunged plot in the wheat-field, it is probable that the percentage of that substance in the surface-soil of the dunged barley plot has, during the 20 years, been nearly doubled. Yet, mixtures of mineral manure and ammonia-salts, or nitrate of soda, supplying nitrogen in so much less quantity, but in a more readily available condition, frequently gave about the same, and sometimes more, produce than the dung. It is obvious, too, that the large amount of nitrogen accumulated in the soil of the dunged plot is in a far less available or effective condition than the much smaller quantities annually supplied as ammonia-salts or nitrate of soda.

In order to ascertain in what degree the accumulated nitrogen and other constituents will be annually available, and for what length of time any residue will remain effective, the dunged plot has, since the removal of the twentieth crop, been divided into two portions—one to receive dung annually, as before, and the other to be left unmanured, probably until the produce on it approximates to that of the continuously unmanured plot.

The following Table shows the results obtained by the annual application of 14 tons of dung per acre, for barley, and for wheat,

respectively. As before, the produce is, for easy comparison, given in pounds, and that of the wheat is averaged over the whole 28, the first 20, and last 20 years.

TABLE XXVIII.—Average Annual Produce of Wheat, and of Barley, by 14 tons Farmyard Manure per Acre, per Annum.

	AVERAGE ANNUAL PRODUCE, &c.						
	First Half of Period.	Second Half of Period.	Total Period.	Second Period over (or under —) First Period.	Barley over (or under —) Wheat.		
					First Half of Period.	Second Half of Period.	Total Period.
Total Corn, per Acre.							
Wheat :—	lbs.	lbs.	lbs.	Per Cent.	lbs.	lbs.	lbs.
28 years, 1844-1871	1953	2335	2144	19·6	588	660	624
20 years, 1844-1863	1757	2395	2076	36·3	784	600	692
20 years, 1852-1871	2145	2385	2265	11·2	396	610	503
Barley :—							
20 years, 1852-1871	2541	2995	2768	17·9			
Straw (and Chaff), per Acre.							
Wheat :—							
28 years, 1844-1871	3332	3801	3567	14·1	—348	—454	—402
20 years, 1844-1863	3071	3960	3515	28·9	—87	—613	—350
20 years, 1852-1871	3795	3803	3799	0·2	—811	—456	—634
Barley :—							
20 years, 1852-1871	2984	3347	3165	12·2			
Total Produce (Corn, Straw, and Chaff), per Acre.							
Wheat :—							
28 years, 1844-1871	5285	6136	5711	16·1	240	206	222
20 years, 1844-1863	4828	6355	5591	31·6	697	—13	342
20 years, 1852-1871	5940	6188	6064	4·2	—415	154	—131
Barley :—							
20 years, 1852-1871	5525	6342	5933	14·8			

The produce of wheat as well as of barley was considerably higher over the later than over the earlier years; but the rate of increase was very much less over the last 20 than over the first 20 of the total 28 years. It may be mentioned here, in passing, that in only 4 of the 28 years has the produce of wheat-grain been higher on the dunged than on any of the artificially manured plots, namely, in 1855, 1859, 1866, and 1871; and in every year it has been surpassed in weight of straw, and of total produce (corn and straw together), on one or more of the artificially manured plots.

As without manure, so with farmyard manure, over whichever period the wheat is averaged, the barley gives a considerably greater quantity of corn, but considerably less straw, than the wheat. Of total produce, however, when the wheat is averaged over the whole 28 years, the barley gives (over 20 years) an average annual excess of 222 lbs. over the wheat; when the first 20 years of wheat is taken the excess of barley is 342 lbs. per acre per annum; but when both wheat and barley are taken over the same 20 years (in the case of the wheat after 8 preceding years of the same manuring and cropping), the barley gives a slight average annual deficiency of total produce, namely, 131 lbs.*

From these facts it may be concluded that, excepting differences due to season, or other incidental causes, a given amount of farmyard manure annually applied to a given soil will, when averaged over a sufficient period, yield identical amounts of total produce of the autumn-sown and autumn-manured wheat, and of the spring-sown and spring-manured barley.

The practice of applying 14 tons of farmyard manure per acre, per annum, is, it is true, as unusual as that of growing either wheat or barley so many years in succession on the same land. Nevertheless, the results of such an experiment are of much interest. They may be briefly summarised as follows:—With the great accumulation of constituents within the soil, the produce of both crops is higher in the later than in the earlier years; much more corn, but much less straw, was obtained with the spring-sown and spring-manured barley, than with the autumn-sown and autumn-manured wheat; but the two crops gave almost identical amounts of average annual total produce (corn and straw together). Notwithstanding that the dung supplied several times as much nitrogen, and more of all other constituents, its produce seldom exceeded that of some of the artificial mixtures of mineral manure and ammonia-salts, or nitrate of soda.

Lastly in regard to the effects of the farmyard manure, attention has been called (pp. 55–57 and 67) to the influence of the accumulated matter on the physical condition of the soil, increasing its porosity, enabling it to retain more moisture, and rendering the crop much less liable to injury from adverse climatic conditions, and especially from drought. Future experi-

* The general result is the same whether the acreage *produce* of the two crops be compared, as above, or only the *increase* of produce by manure; and as in adopting the increase as the basis of comparison, the diminution of produce without manure (which moreover was different for the two crops) would be a necessary element affecting the calculation, it is concluded that, for the purpose in view, the comparison of the *produce* of the two crops is less open to objection than that of the *increase*.

ment will show in what degree the accumulated residue from the previous manuring is effective for succeeding crops ; and the effects of the different artificial manures now to be considered, will show to what constituents of the dung the increase of produce it has yielded has most probably been mainly due.

Average Annual Produce by purely Mineral Manure.

Under this head attention will chiefly be directed to the results obtained on the plots, and by the manures, as under :—

Plot 2 O—Superphosphate of Lime.

Plot 3 O—"Mixed Alkali-salts"—a mixture of sulphates of Potass, Soda, and Magnesia.

Plot 4 O—"Mixed Mineral Manure"—a mixture of the "Superphosphate of Lime," and the "mixed Alkali-salts."

Table XXIX. shows the average annual produce and increase by these manures. (See next page.)

The first point to remark is that, as without manure and with farmyard manure, so with these purely mineral manures, the weight per bushel of dressed corn is, in each case, considerably higher over the second than over the first 10 years. The proportion of corn to straw is also higher over the later years. This result is doubtless in great measure due to season. Still it is clear that in these points of *quality* there is no deterioration in the crop.

In point of *quantity*, however, the result is very different. There is, with each of the manures, a very considerable falling off in the average annual amount of corn, of straw, and of total produce, over the second as compared with the first 10 years ; and rather more where the salts of potass, soda, and magnesia, are used, whether alone or in admixture with superphosphate, than where the superphosphate is used alone. Where the superphosphate and mixed alkali-salts are used together, the greater falling off in the later as compared with the earlier years would seem to be connected with a higher produce by that manure than by the superphosphate alone in the earlier years ; whilst, in the later years, the produce by the two manures approximates more closely. Lastly on this point, the average annual increase over the unmanured produce is not, by either manure, widely different over the two periods ; but where the superphosphate and the mixed alkali-salts are each used separately, the increase is rather greater, and where they are used together rather less, over the second 10 years—indicating a slightly less rate of decline than without manure with the two former, and a slightly greater decline with the more complete manure—accounted for by its proportionally greater increase over the earlier years.

TABLE XXIX.—Average Annual Produce, and Increase, by purely Mineral Manures.

Plots	MANURES PER ANNUM,	AVERAGE ANNUAL PRODUCE, &c.				INCREASE OVER (or under —) UNMANURED (Plots 1 O and 6-1.)		
		First 10 Years, 1852-'61.	Second 10 Years, 1862-'71.	Total Period, 20 Years, 1852-'71.	Second 10 Years over (or under —) First 10.	First 10 Years, 1852-'61.	Second 10 Years, 1862-'71.	Total Period, 20 Years, 1852-'71.

Dressed Corn, per Acre—Bushels.

					Per Cent.			
2 O	Superphosphate ..	28	23½	25½	—17·0	4½	5	4½
3 O	Mixed Alkali-salts ..	24½	20½	22½	—19·1	1½	1½	1½
4 O	{ Superphosphate and Mixed Alkali-salts }	30½	24½	27½	—20·0	6½	6½	6½

Total Corn, per Acre—lbs.

2 O	Superphosphate ..	1562	1317	1439	—15·7	214	289	252
3 O	Mixed Alkali-salts ..	1396	1139	1268	—18·4	48	112	80
4 O	{ Superphosphate and Mixed Alkali-salts }	1712	1387	1550	—19·0	365	360	363

Straw (and Chaff), per Acre—Cwts.

2 O	Superphosphate ..	14½	11½	13½	—20·2	1½	1½	1½
3 O	Mixed Alkali-salts ..	13½	10½	12½	—22·5	½	½	½
4 O	{ Superphosphate and Mixed Alkali-salts }	16½	12½	14½	—21·7	2½	2½	2½

Total Produce (Corn, Straw, and Chaff), per Acre—lbs.

2 O	Superphosphate ..	3223	2639	2931	—18·1	338	439	389
3 O	Mixed Alkali-salts ..	2944	2338	2641	—20·6	59	138	99
4 O	{ Superphosphate and Mixed Alkali-salts }	3517	2807	3162	—20·2	632	607	621

Weight per Bushel of Dressed Corn—lbs.

2 O	Superphosphate ..	52·1	54·4	53·2	4·4	0·6	1·1	0·8
3 O	Mixed Alkali-salts ..	51·8	54·3	53·0	4·8	0·3	1·0	0·6
4 O	{ Superphosphate and Mixed Alkali-salts }	52·3	54·6	53·4	4·4	0·8	1·3	1·0

Corn to 100 Straw.

2 O	Superphosphate ..	93·8	100·4	97·1	7·0	5·9	12·0	9·0
3 O	Mixed Alkali-salts ..	90·0	94·7	92·4	5·2	2·1	6·3	4·3
4 O	{ Superphosphate and Mixed Alkali-salts }	95·1	97·7	96·4	2·7	7·2	9·3	8·3

Over the whole period, the average annual produce by superphosphate of lime alone, is $25\frac{1}{2}$ bushels of dressed corn, and $13\frac{1}{2}$ cwts. of straw; by the mixed alkali-salts alone, $22\frac{1}{2}$ bushels of dressed corn, and $12\frac{1}{2}$ cwts. of straw; and by the two manures together, $27\frac{1}{2}$ bushels of corn, and $14\frac{1}{2}$ cwts. of straw. The unmanured produce being 21 bushels of corn, and 12 cwts. of straw, the average annual increase is, by the superphosphate alone, $4\frac{1}{2}$ bushels of corn, and $1\frac{1}{2}$ cwt. of straw; by the mixed alkali-salts, $1\frac{1}{2}$ bushel of corn, and $\frac{1}{2}$ cwt. of straw; and by the mixture of the two, $6\frac{1}{2}$ bushels of corn, and $2\frac{1}{2}$ cwts. of straw.

Neither of these purely mineral manures has, then, sufficed to yield anything like a fair crop of barley. The mixed alkali-salts alone have given scarcely any increase at all. It was, therefore, not in an available supply of potass, soda, or magnesia, that the soil was rendered relatively deficient, either by the previous ordinary cropping, or by the continuous growth of barley. Superphosphate of lime alone gave but little, though still notably more increase than the mixed alkali-salts. It would appear, therefore, that there was, within the range of the roots, a greater relative deficiency of available phosphoric acid than of available alkalies. The mixture of the two manures, again, gave slightly more increase than either, or than both, used separately.

The explanation of the effects of these mineral manures, and of the great falling off in the produce, not only by them, but without manure, probably is, that in each case the produce has been limited by the supply of available nitrogen accumulated within the soil, whether from previous cultivation, manuring, and cropping, or by annual deposition and absorption; and that, with the increased supplies of available mineral matter near the surface, root-development has been more or less increased, possession thus acquired of a greater range of soil, and, with this, access obtained to more of its stored-up nitrogen. On this view, the "condition" of the soil, as distinguished from its normal or natural fertility, is at any rate so far as available nitrogen is concerned, being gradually worked out by the growth of the crop, whether without manure, or with the purely mineral manures; and it remains to be seen whether or not the point of normal annual produce has yet been reached.

There are two other plots receiving annually mineral manure alone; namely 5 O, and M; the full particulars of which will be found in the Appendix Tables. They are much smaller, and at the opposite end of the field from the other mineral-manured plots, and the results seem not altogether comparable with those of the latter, though there is less reason to suppose that they are not so with one another. Plot 5 O has received annually super-

phosphate of lime and sulphate of potass (that is excluding sulphates of soda and magnesia); and Plot M has received superphosphate, and sulphates of soda and magnesia (that is excluding sulphate of potass).

The mixture of superphosphate and potass-salt has given an annual average of slightly more corn, but no more straw, than the superphosphate and soda and magnesia salts, without potass. The produce by both manures has fallen off over the later as compared with the earlier years, so far as corn is concerned; but by that including potass it has done so more than by the one without it; and whilst by the manure containing potass, the produce of straw also has fallen off, that by the soda and magnesia without potass has even increased in straw during the later years. Taken over the whole period, the mixture of superphosphate and potass-salt has given annually about $1\frac{1}{4}$ bushel more corn, but only exactly the same amount of straw, as that with soda and magnesia, but without potass. The crop was, however, in both cases most miserable; in the one only $22\frac{1}{4}$, in the other only $21\frac{1}{4}$ bushels of corn, and in both only $12\frac{3}{4}$ cwt. of straw.

It may be concluded that there was in neither case any deficiency of *mineral* matter for such meagre crops; but that in the one the relatively liberal supply of potass favoured seeding tendency, and in the other the salts of soda and magnesia, whether by action on the soil, or more directly on the development of the plant itself, favoured some increase of plant, without corresponding seeding tendency. Evidence of the effects of superphosphate and potass-salts, compared with superphosphate, potass, soda, magnesia-salts will be forthcoming when the results obtained with these mixtures in conjunction with nitrogenous manures are considered.

It will be of interest to compare the effects of purely mineral manures on wheat, and on barley. The following Table (XXX.) shows the effects of the same "mixed mineral manure," used over the same period of 20 years, with the two crops. As in the case of the experiment with farmyard manure, the produce, not the increase, of the two crops is taken for illustration, and, *mutatis mutandis*, for similar reasons. But it should be further explained, that whilst in the case of the wheat plot, 8 crops, variously but upon the whole liberally manured, had already been taken, in that of the barley the period commences with the first year of the experiments.

As without manure, and with farmyard manure, so with the mixed mineral manures, barley yields considerably more grain than wheat—in fact, not far short of one-half more. On the other hand, it gives rather less straw, but of total produce (corn and straw together) considerably more than the wheat. It may be

added that, although the figures and their relations would differ, more or less, if the increase instead of the produce were taken for comparison, yet the general results would be the same.

TABLE XXX.—Average Annual Produce of Wheat and of Barley by purely Mineral Manure.

MANURES PER ACRE, PER ANNUM:— 3½ Cwts. Superphosphate of Lime. 200 lbs. (1) Sulphate Potass. 100 lbs. (2) Sulphate Soda. 100 lbs. Sulphate Magnesia.	AVERAGE ANNUAL PRODUCE, &c.			
	First 10 Years, 1852-'61.	Second 10 Years, 1862-'71.	Total Period, 20 Years, 1852-'71.	Second 10 Years over (or under —) First 10.
Total Corn, per Acre—lbs.				
Wheat (Plot 5) 20 years, 1852-1871	1149	987	1068	Per Cent. — 14·1
Barley (Plot 4 O) 20 years, 1852-1871	1712	1387	1550	— 19·0
Barley over (or under —) Wheat	563	400	482	
Straw (and Chaff), per Acre—lbs.				
Wheat (Plot 5) 20 years, 1852-1871	1919	1437	1678	— 25·1
Barley (Plot 4 O) 20 years, 1852-1871	1805	1420	1612	— 21·3
Barley over (or under —) Wheat	— 114	— 17	— 65	
Total Produce (Corn, Straw, and Chaff), per Acre—lbs.				
Wheat (Plot 5) 20 years, 1852-1871	3068	2424	2746	— 21·0
Barley (Plot 4 O) 20 years, 1852-1871	3517	2807	3162	— 20·2
Barley over (or under —) Wheat	449	383	417	

(1) 300 lbs. for the first 6 years of barley, and first 7 years of wheat.

(2) 200 lbs. for the first 6 years of barley, and first 7 years of wheat.

The result itself is remarkable from several points of view. The wheat plot, although it had previously yielded 8 experimental crops, had, during that time, received considerable quantities of mineral manure and ammonia-salts, and some rape-cake also. It would be supposed, therefore, that there was more "condition" to work out of it than out of the barley plot. Then again, the assumed greater root-range of the autumn-sown wheat, than of the spring-sown barley, and the longer period of growth of the autumn-sown crop, would, it might be concluded, give it a greater command over the stores within the soil. Further, calculation shows that the barley crop would actually contain more nitrogen than the wheat.

Is the less result with mineral manures on wheat than on barley due to the dilution and distribution of the autumn-sown manures by the winter rains, and to their having acquired a comparatively insoluble condition, resulting in a less active root-development in the upper, and more highly nitrogenous layers of the soil, when growth commences in the spring? Is there, consequently, a more rapid exhaustion of the accumulated nitrogen within the soil by the barley than by the wheat? Or, does the pipe-draining of the wheat-field render the drainage the more free, and so cause a greater washing out of nitrogenous compounds in the winter; even from the plots where none are artificially applied? It is at any rate consistent with the supposition that there is a more rapid exhaustion of the nitrogen accumulated within the soil, by the barley than by the wheat, when each is grown without nitrogenous manure, that, according to calculation it appears probable that, both without manure, and with purely mineral manure, the barley has carried off more nitrogen from a given area than the wheat, whilst it has, under both conditions, declined more rapidly in annual produce of corn, and without manure in *total* produce also.

The general result with the purely mineral manures is—that superphosphate of lime gave more increase of barley than a mixture of salts of potass, soda, and magnesia; that neither the one nor the other, nor the mixture of all, sufficed to raise the produce to anything like a fair crop; and that, with either, the crop fell off considerably over the later years. Nevertheless, both the produce and the increase of barley by the mixed mineral manure were considerably greater than those of wheat by the same manure. It may be concluded that the exhaustion which the soil undoubtedly suffered, was not connected with a relative deficiency of any of the constituents which these mineral manures supplied. The results next to be considered will show in what the exhaustion really did consist.

Average Annual Produce by Ammonia-salts alone, or Nitrate of Soda alone.

Of the four experiments under this head, the first to be noticed are those on—

Plot 1 A with 200 lbs. of ammonia-salts per acre per annum, for 20 years, 1852-1871.

Plot 1 N with 275 lbs. nitrate of soda per acre per annum, for 19 years, 1853-1871.

200 lbs. of ammonia-salts and 275 lbs. of nitrate of soda, are estimated to supply the same amount of nitrogen, namely 41 lbs. = 50 lbs. of ammonia. But it must be noted that the plot subsequently

having nitrate received, in the first year of the twenty, $3\frac{1}{2}$ cwts. of superphosphate of lime, and 300 lbs. of sulphate of potass, per acre. These mineral manures gave no increase whatever in the year of their application; but, under the exhausting process of afterwards using nitrogenous manures alone for so many years in succession, they have doubtless had considerable effect on the succeeding crops. Hence, unfortunately, the two experiments, the one with a given amount of nitrogen as ammonia-salts for 20 years, and the other with the same amount as nitrate of soda for the last 19 of the 20 years, are not strictly comparable. (Table XXXI., next page.)

In the first place, notwithstanding the great demand made on the mineral resources of the soil, by applying ammonia-salts alone year after year, there is considerably less falling off in the produce over the second as compared with the first ten years, under such treatment, than by the application of mixed mineral manure alone every year. And not only so: whilst, over the twenty years, the average annual produce was, by the mixed mineral manure only $27\frac{1}{2}$ bushels of corn and $14\frac{3}{8}$ cwts. of straw, that by the 200 lbs. of ammonia-salts alone was $32\frac{1}{2}$ bushels of corn, and $18\frac{1}{2}$ cwts. of straw. In other words, whilst the *increase* of produce by the mixed mineral manure alone averaged, over twenty years, only $6\frac{1}{2}$ bushels of corn and $2\frac{1}{2}$ cwts. of straw, per acre per annum, that by this comparatively small quantity of ammonia-salts alone averaged, over the same period, $11\frac{1}{2}$ bushels of corn, and $6\frac{1}{2}$ cwts. of straw.

Comparing the result by ammonia-salts for 20 years, with that by the same quantity of nitrogen as nitrate of soda for 19 years, the average annual produce and increase are $5\frac{1}{2}$ bushels of corn, and $4\frac{5}{8}$ cwts. of straw, more by the nitrate than by the ammonia-salts.

It is obvious that, owing to the greater solubility, and more rapid distribution in the soil and subsoil, of the nitrate or its products of decomposition, it will be the more liable to loss by drainage when there is an excess of rain. On the other hand, as already referred to (p. 56), the subsoil in its case becomes more disintegrated, therefore more porous, more retentive of moisture in a favourable condition, and more permeable by the roots. It is, probably, in part due to this action that the effects of a given amount of nitrogen as nitrate of soda increase from year to year compared with those of an equivalent application as ammonia-salts. How much of the greater effect of the nitrate in the experiment in question may be due to this action, and how much to the supply of mineral manure to the nitrated plot in the first year, it is impossible to determine.

On the latter point it may be mentioned, that the amounts of

Plots.	MANURES PER ACRE, PER ANNUM.	AVERAGE ANNUAL PRODUCE, &c.				AVERAGES ANNUAL INCREASE OVER (or under —) UNMANURED (Plots 1 O and 6-1.)		
		First Half of Period. (1)	Second Half of Period.	Total Period. (1)	Second Period (over or under —) First Period.	First Half of Period. (1)	Second Half of Period.	Total Period (1)
Dressed Corn, per Acre—Bushels.								
1 A	200 lbs. Ammonia-salts; 20 years, 1852-1871 ..	33½	31½	32½	Per Cent. — 6·7	9½	13½	11½
1 N	275 lbs. Nitrate Soda; 19 years, 1853-1871 ..	37½	37½	37½	— 1·3	14½	18½	16½
Total Corn, per Acre—lbs.								
1 A	200 lbs. Ammonia-salts; 20 years, 1852-1871 ..	1908	1771	1840	— 7·2	560	744	652
1 N	275 lbs. Nitrate Soda; 19 years, 1853-1871 ..	2124	2108	2116	— 0·8	806	1081	950
Straw (and Chaff), per Acre—Cwts.								
1 A	200 lbs. Ammonia-salts; 20 years, 1852-1871 ..	19½	17½	18½	— 12 0	6	6½	6½
1 N	275 lbs. Nitrate Soda; 19 years, 1853-1871 ..	23½	22½	22½	— 3·7	10	11½	10½
Total Produce (Corn, Straw, and Chaff), per Acre—lbs.								
1 A	2400 lbs. Ammonia-salts; 20 years, 1852-1871 ..	4119	3719	3919	— 9·7	1234	1519	1376
1 N	275 lbs. Nitrate Soda; 19 years, 1853-1871 ..	4745	4628	4683	— 2·5	1928	2428	2191
Weight per Bushel of Dressed Corn—lbs.								
1 A	200 lbs. Ammonia-salts; 20 years, 1852-1871 ..	51·2	53·0	52·1	3·5	— 0·3	— 0·3	— 0·3
1 N	275 lbs. Nitrate Soda; 19 years, 1853-1871 ..	51·6	53·7	52·7	4·1	0·1	0·4	0·3
Corn to 100 Straw.								
1 A	200 lbs. Ammonia-salts; 20 years, 1852-1871 ..	86·4	91·9	89·2	6·4	— 1·5	3·5	1·1
1 N	275 lbs. Nitrate Soda; 19 years, 1853-1871 ..	81·3	86·0	83·7	5·8	— 6·9	— 2·4	— 4·6

(1) For the Nitrate plot (1 N), the averages for the first period are for only 9 years, and for the total period for only 19 years.

(1) For the Nitrate plot (1 N), the averages for the first period are for only 9 years, and for the total period for only 19 years.

phosphoric acid and potass applied in the first year, but which gave no increase in that year, were sufficient, if still present and available, to supply those constituents for more than the excess of corn and straw obtained on the nitrate, as compared with the ammonia-plot. Further, the experiments with wheat have afforded abundant evidence, that phosphates and potass-salts previously applied, have been effective for 20 years or more, when nitrogenous manures have been afterwards supplied, to work them out, so to speak. There can be little doubt, indeed, that part, at any rate, of the greater effect of the nitrate in the experiment in question, was really due to the supply of mineral constituents in the first year.

The results next to be considered show the effects of double the above amounts of ammonia-salts alone, or nitrate of soda alone, but applied for a few years only as under :—

Plot 1. A. A :—

6 years, 1852-1857, 400 lbs. ammonia-salts, per acre, per annum.

Plot 2. N :—

1 year, 1852, $3\frac{1}{2}$ cwts. superphosphate, 300 lbs. sulphate potass ;

5 years, 1853-1857, 550 lbs. nitrate of soda.

Thus, as in the previous comparison, the two plots received corresponding amounts of nitrogen as ammonia-salts, and as nitrate of soda, respectively, for a series of years ; but whilst the ammonia plot received the double dressing of ammonia-salts, in the first as well as the succeeding 5 years, the nitrate plot received phosphates and potass without nitrate in the first year, and the double quantity of nitrate in the succeeding 5 years.

Table XXXII. (see next page) shows the produce obtained, and also the increase, both over the unmanured produce, and over that by the smaller amounts of ammonia-salts, or nitrate, in the corresponding years.

Thus, there is an average annual produce of 46 bushels of corn, and $28\frac{1}{2}$ cwts. of straw, by the application of 400 lbs. of ammonia-salts alone for 6 years ; also of 48 bushels of corn, and $31\frac{1}{2}$ cwts. of straw, by the same amount of nitrogen as nitrate of soda alone for 5 years (but succeeding a dressing of superphosphate and sulphate of potass). The produce by the double amount of ammonia-salts alone represents an average annual increase over the unmanured produce of $17\frac{7}{8}$ bushels of corn, and $12\frac{1}{4}$ cwts. of straw ; and of $7\frac{3}{8}$ bushels of corn, and $5\frac{7}{8}$ cwts. of straw over that by half the quantity of ammonia-salts for the same period. In like manner the produce by the double amount of nitrate of soda alone, represents an annual total increase of $19\frac{7}{8}$

bushels of corn, and $15\frac{3}{8}$ cwts. of straw ; and an increase over the produce by the single amount of nitrate, of $5\frac{1}{8}$ bushels of corn, and 6 cwts. of straw.

TABLE XXXII.—Average Annual Produce and Increase by 400 lbs. Ammonia salts alone, or 550 lbs. Nitrate of Soda alone.

Plots.	MANURES PER ACRE, PER ANNUM.	Average Annual Produce.	AVERAGE ANNUAL INCREASE.	
			Over Unmanured (Plots 1 O and 6-1.)	1 AA over 1 A. 2 N over 1 N.
Dressed Corn per Acre—Bushels.				
1 AA	400 lbs Ammonia-salts; 6 years, 1852-1857	46	17½	7½
2 N	550 lbs. Nitrate of Soda; 5 years, 1853-1857	48	19½	5½
Total Corn per Acre—lbs.				
1 AA	400 lbs. Ammonia-salts; 6 years, 1852-1857	2603	1005	412
2 N	550 lbs. Nitrate of Soda; 5 years, 1853-1857	2666	1070	302
Straw (and Chaff) per Acre—Cwts.				
1 AA	400 lbs. Ammonia-salts; 6 years, 1852-1857	28½	12½	5½
2 N	550 lbs. Nitrate of Soda; 5 years, 1853-1857	31½	15½	6
Total Produce (Corn, Straw, and Chaff) per Acre—lbs.				
1 AA	400 lbs. Ammonia-salts; 6 years, 1852-1857	5794	2371	1066
2 N	550 lbs. Nitrate of Soda; 5 years, 1853-1857	6198	2794	972
Weight per Bushel of Dressed Corn—lbs.				
1 AA	400 lbs. Ammonia-salts; 6 years, 1852-1857	50·7	— 1·0	— 0·8
2 N	550 lbs. Nitrate of Soda; 5 years, 1853-1857	50·9	— 0·7	— 1·0
Corn to 100 Straw.				
1 AA	400 lbs. Ammonia-salts; 6 years, 1852-1857	82·5	— 5·7	— 4·4
2 N	550 lbs. Nitrate of Soda; 5 years, 1853-1857	75·4	— 13·4	— 7·4

We have here, then, by the application of ammonia-salts alone, or of nitrate of soda alone, an average annual produce. over 5 or

6 consecutive years, of 46 or 48 bushels of barley; or considerably more than the amount assumed (p. 9) to be a good produce under ordinary rotation and cultivation. These amounts are also fully one-third more than was obtained by purely mineral manure over the same period.

It was found that these double dressings were too heavy, the crops frequently being much laid; and hence, after the first 6 years of the experiments, the quantities were reduced to one-half, that is, to the same as on plots 1 A and 1 N. For many subsequent years, however, the plots previously receiving the larger amounts, whether alone, or with mineral manure (as presently to be noticed), continued to yield more produce than the plots receiving the smaller quantity from the commencement. But as the effects of the unexhausted residue from previous manuring upon succeeding crops will be considered separately and in detail in Section IV. no more need be said on the point in this place.

It would be interesting to compare the effects of purely nitrogenous manures on wheat and on barley; but as the experiments with such manures on the two crops are not as parallel as is desirable, either as regards the previous history of the plots, the quantities applied, or the periods and duration of the experiments, the comparison might be misleading unless given with much explanation and qualification. The omission is, however, of the less consequence, as we shall be enabled to compare the effects on the two crops of a mixture of ammonia-salts and mineral manure together, which in fact is of much greater practical importance.

The practice of growing barley for so many years in succession on the same land by any means whatever, is not, it is true, recommended for adoption in practical agriculture; and still less desirable would it be so to grow it by means of ammonia-salts alone, or nitrate of soda alone. But the extraordinary results which have been recorded are not the less instructive and important, or of less practical value, on that account.

It is of no little interest to know, that on a soil, consisting of a somewhat heavy loam with a clayey subsoil, and of only moderate corn-yielding capabilities, purely mineral manures will not yield anything like a fair crop of wheat or barley; but that, on the same soil, a comparatively small quantity of purely nitrogenous manures has yielded, for twenty years in succession, not much less barley than the average crop of the country; and that a larger amount has given, over 6 consecutive seasons, considerably more than an average crop. This is knowledge acquired of the available mineral resources of such a soil, which analysis would not have afforded; and which supplies, if not examples for exact imitation, at any rate a very sound basis for deduction in regard to actual practice.

Average annual Produce by Ammonia-salts or Nitrate of Soda, with mineral Manure in addition.

The first set of experiments to be noticed here, includes four plots, each of which has received 200 lbs. ammonia-salts per acre per annum, throughout the twenty years, but each with a different mineral manure in addition. The mineral manures, here used in admixture with nitrogenous manures, are the same as in the experiments with purely mineral manures, which have already been considered. As only much abbreviated descriptions of the manures can be given in the Table (see next page), they are described in full below:—

- Plot 2 A—200 lbs. Ammonia-salts, and $3\frac{1}{2}$ cwts. Superphosphate of Lime.
Plot 3 A—200 lbs. Ammonia-salts, and mixed Alkali-salts, —namely, a mixture of 200 lbs.* Sulphate Potass, 100 lbs.† Sulphate Soda, 100 lbs. Sulphate Magnesia.
Plot 4 A—200 lbs. Ammonia-salts, $3\frac{1}{2}$ cwts. Superphosphate, and the “mixed Alkali-salts.”
Plot 5 A—200 lbs. Ammonia-salts, $3\frac{1}{2}$ cwts. Superphosphate, and 200 lbs.* Sulphate Potass.

The produce is averaged over the first 10, the second 10, and the 20 years. The increase is calculated over the produce without manure, and also, in each case, over that by the corresponding mineral manure without ammonia-salts;—that is 2 A over 2 O, 3 A over 3 O, 4 A over 4 O, and 5 A over 5 O.

It is remarkable that, instead of, as without manure, with purely mineral manure, or with purely nitrogenous manure, a considerable falling off in the second compared with the first half of the total period, there is, with ammonia-salts and mineral manure together (though without silica), in each case a more or less increased produce of corn over the second compared with the first 10 years. On the other hand, there is in two out of the four cases a slight, and in a third a more considerable, deficiency of straw over the later period; and it is only in that one instance that there is any material diminution in quantity of total produce, and then little more than 5 per cent.

So far as quality of the produce is concerned, both weight per bushel of dressed corn, and proportion of corn to straw, are in every case higher over the second than the first 10 years.

It has been concluded (pp. 78–9) that the second period was, so far as the seasons themselves are concerned, the more favourable for the production of corn, but the less for that of straw and total produce.

* 300 lbs. the first six years, 200 lbs. afterwards.

† 200 lbs. the first six years, 100 lbs. afterwards.

TABLE XXXIII.—Average Annual Produce and Increase by 200 lbs. Ammonia-salts, and Mineral Manure.
Twenty years, 1852-1871.

Plots.	MANURES PER ACRE, PER ANNUM.	AVERAGE ANNUAL PRODUCE, &c.				AVERAGE ANNUAL INCREASE, 20 YEARS.	
	200 lbs. Ammonia-salts, and Mineral Manures as under—	First 10 Years, 1852-'61.	Second 10 Years, 1862-'71.	Total 20 Years, 1852-'71.	Second 10 Years over (or under —) First 10.	Over Mean Unmanured.	Over Corre- sponding Mineral Manure.
Dressed Corn per Acre—Bushels.							
2 A	Superphosphate ..	45½	48½	47½	Per Cent. 6·0	26½	21½
3 A	Mixed Alkali-salts ..	35	35½	35½	0·4	14½	12½
4 A	{ Superphosphate and Mixed Alkali-salts }	46½	46½	46½	0·5	25½	18½
5 A	{ Superphosphate and Sulphate Potass .. }	43½	44½	44½	3·2	23½	21½
Total Corn per Acre—lbs.							
2 A	Superphosphate ..	2563	2762	2662	7·8	1474	1223
3 A	Mixed Alkali-salts ..	1989	1995	1992	0·3	804	724
4 A	{ Superphosphate and Mixed Alkali-salts }	2593	2668	2630	2·9	1442	1080
5 A	{ Superphosphate and Sulphate Potass .. }	2426	2584	2505	6·5	1317	1212
Straw (and Chaff) per Acre—Cwts.							
2 A	Superphosphate ..	27½	27½	27½	-1·5	15½	14½
3 A	Mixed Alkali-salts ..	21½	19½	20½	-9·8	8½	8½
4 A	{ Superphosphate and Mixed Alkali-salts }	28½	28	28½	-2·9	16½	14½
5 A	{ Superphosphate and Sulphate Potass .. }	27½	28½	28	1·5	15½	15½
Total Produce (Corn, Straw, and Chaff) per Acre—lbs.							
2 A	Superphosphate ..	5683	5837	5760	2·7	3218	2829
3 A	Mixed Alkali-salts ..	4434	4200	4317	-5·3	1775	1676
4 A	{ Superphosphate and Mixed Alkali-salts }	5827	5808	5817	-0·3	3275	2655
5 A	{ Superphosphate and Sulphate Potass .. }	5542	5747	5644	3·7	3102	2962
Weight per Bushel of Dressed Corn—lbs.							
2 A	Superphosphate ..	51·8	55·1	53·5	6·4	1·1	0·3
3 A	Mixed Alkali-salts ..	51·5	54·1	52·8	5·0	0·4	-0·2
4 A	{ Superphosphate and Mixed Alkali-salts }	52·2	55·7	54·0	6·7	1·6	0·6
5 A	{ Superphosphate and Sulphate Potass .. }	51·9	55·7	53·8	7·3	1·4	0·3
Corn to 100 Straw.							
2 A	Superphosphate ..	81·9	91·8	86·8	12·1	-1·3	-10·3
3 A	Mixed Alkali-salts ..	81·4	91·3	86·3	12·2	-1·8	-6·1
4 A	{ Superphosphate and Mixed Alkali-salts }	79·9	86·4	83·2	8·1	-4·9	-13·2
5 A	{ Superphosphate and Sulphate Potass .. }	77·8	83·1	80·4	6·8	-7·7	-15·8

The evidence taken as a whole, therefore, gives no indication of any deterioration in either the quantity or the quality of the produce as the result of the continuous growth of the crop, provided the necessary constituents are supplied by manure.

It is seen that whilst the average annual produce over the twenty years is, with ammonia-salts and superphosphate of lime $47\frac{1}{4}$ bushels of dressed corn and $27\frac{5}{8}$ cwts. of straw, with the same quantity of ammonia-salts and a mixture of sulphates of potass, soda, and magnesia, it is only $35\frac{1}{4}$ bushels of corn, and only $20\frac{3}{4}$ cwts. of straw. Even with the ammonia-salts and both the superphosphate and the "mixed alkali-salts," it is only $46\frac{3}{8}$ bushels of corn, and $28\frac{1}{2}$ cwts. of straw; or rather less corn, though rather more straw, and total produce, than with the ammonia-salts and superphosphate without the salts of potass, soda, and magnesia. It is further remarkable that the yield of corn has increased more over the later period where the superphosphate was used without, than where in conjunction with the mixed alkali-salts. The details show, however, that the produce, at any rate of straw, where the mixed alkali-salts and the superphosphate are used together, has been of late years somewhat gaining upon that where the superphosphate is used alone.

It may be mentioned, though not shown in the Table, that the *increase* over the unmanured, or over the corresponding mineral manured produce, is much greater over the second period compared with the first, than is the augmentation of the *actual produce* itself. This is explained by the fact that the produce without manure, or by the mineral manures alone, was much the less over the later period, and hence, though there was much the same actual amount of produce over the two periods when ammonia was also used, still the increase over that without ammonia is much the greater.

Over the whole period of twenty years the average annual increase of produce due to the combined action of mineral and nitrogenous manures is, with the ammonia-salts and superphosphate, $26\frac{1}{8}$ bushels of corn and $15\frac{1}{2}$ cwts. of straw; with the same and the mixed alkali-salts in addition, $25\frac{3}{8}$ bushels of corn and $16\frac{3}{8}$ cwts. of straw; with the same and sulphate of potass (without soda and magnesia) $23\frac{1}{8}$ bushels of corn, and $15\frac{7}{8}$ cwts. of straw; but with the ammonia-salts and salts of potass, soda and magnesia (without superphosphate) only $14\frac{1}{8}$ bushels of corn and $8\frac{5}{8}$ cwts. of straw. Or, if the increase be reckoned over the produce by the corresponding mineral manure without ammonia, in which case it is the increase due to the ammonia itself that is more nearly represented, it is, when used with superphosphate of lime $21\frac{1}{2}$ bushels of corn, and $14\frac{1}{4}$ cwts. of straw; when with superphos-

phate and the mixed alkali-salts 18 $\frac{7}{8}$ bushels of corn, and 14 $\frac{1}{8}$ cwts. of straw; when with the superphosphate and sulphate of potass 21 $\frac{1}{4}$ bushels of corn, and 15 $\frac{5}{8}$ cwts. of straw; but when with the mixed alkali-salts without superphosphate, only 12 $\frac{5}{8}$ bushels of corn and 8 $\frac{1}{2}$ cwts. of straw.

Thus, the effect of a given amount of ammonia is seen to differ very greatly according to the character of the mineral constituents supplied with it. The results clearly show, what common experience also teaches, how effective a manure for barley is superphosphate of lime, provided only there be also a sufficient available supply of nitrogen within the soil. It is, however, as a rule, much less effective with winter-sown than with spring-sown corn-crops; the latter, with their short period of growth, and relatively greater dependence on root-development near the surface, requiring more liberal supplies within a limited range of soil.

Considering the characters of the soil, and the results obtained with other crops, to say nothing of general practical experience, it is only what would be anticipated, that the addition to the ammonia-salts of superphosphate of lime would be much more effective than that of salts of potass, soda, and magnesia; but it is hardly what would be expected that, over twenty years in succession, the soil would yield an average of even rather more corn, only $\frac{7}{8}$ cwt. less straw, and only 57 lbs. less total produce, with ammonia-salts and superphosphate, than with the ammonia-salts, superphosphate, and the mixed alkali-salts together. The illustration is a striking one of the potass-yielding capabilities of such a soil. As already intimated, there are symptoms of a slight change during the last few years; but the fact is of great practical and scientific interest, that by ammonia-salts and superphosphate of lime, without potass or other bases, considerably more than the average barley crop of the country has been obtained for twenty years in succession.

Table XXXIV. (next page) shows the produce and increase obtained by the same mineral manures as those employed in three of the four experiments last considered, but, in each case, with double the amount of ammonia-salts; namely, 400 lbs. per acre per annum, used, however, for only the first six years of the twenty. The increase is given over the produce without manure, over that by the corresponding mineral manures without ammonia, and over that by the corresponding mineral manure with only 200 lbs. of ammonia-salts.

It is obvious that, with an average annual produce of 46 or 47 bushels of barley, over twenty years, by the mineral manures and 200 lbs. of ammonia-salts per acre, the limit of the ripening capabilities of the seasons must have been nearly reached.

TABLE XXXIV.—Average Annual Produce and Increase by 400 lbs. Ammonia-salts, and Mineral Manure.

Six Years, 1852–1857.

Plots.	MANURES PER ACRE, PER ANNUM. 400 lbs. Ammonia-salts, and Mineral Manures as under.	Average Annual Produce. — 6 Years, 1852-'57.	AVERAGE ANNUAL INCREASE, 6 YEARS.		
			Over Mean Unmanured.	Over corresponding Mineral Manures.	Over corresponding Mineral Manures and 200 lbs. Ammonia-salts.
Dressed Corn per Acre—Bushels.					
2 AA	Superphosphate of Lime	49½	21½	18	4½
3 AA	Mixed Alkali-salts	42½	14½	14	3½
4 AA	Superphos. and Mixed Alkali-salts	50½	22½	16½	4½
Total Corn per Acre—lbs.					
2 AA	Superphosphate of Lime	2775	1177	1027	230
3 AA	Mixed Alkali-salts	2441	843	814	169
4 AA	Superphos. and Mixed Alkali-salts	2801	1203	887	205
Straw (and Chaff) per Acre—Cwts.					
2 AA	Superphosphate of Lime	34	17½	17½	5½
3 AA	Mixed Alkali-salts	29½	13½	13½	4½
4 AA	Superphos. and Mixed Alkali-salts	36½	20½	18½	7½
Total Produce (Corn, Straw, and Chaff) per Acre—lbs.					
2 AA	Superphosphate of Lime	6590	3170	2996	872
3 AA	Mixed Alkali-salts	5753	2333	2330	697
4 AA	Superphos. and Mixed Alkali-salts	6874	3454	2948	1011
Weight per Bushel of Dressed Corn—lbs.					
2 AA	Superphosphate of Lime	50·5	— 1·2	— 1·3	— 1·0
3 AA	Mixed Alkali-salts	50·8	— 0·9	— 1·2	— 1·0
4 AA	Superphos. and Mixed Alkali-salts	50·4	— 1·3	— 1·5	— 1·6
Corn to 100 Straw.					
2 AA	Superphosphate of Lime	73·1	— 15·1	— 21·8	— 6·9
3 AA	Mixed Alkali-salts	74·1	— 14·1	— 16·9	— 8·0
4 AA	Superphos. and Mixed Alkali-salts	69·4	— 18·8	— 26·5	— 9·9

Indeed, the double amount of ammonia-salts was found, even when used in conjunction with mineral manure, to be quite excessive, the crops being generally laid; and hence, after six

years' trial, the extra application was discontinued. Under these circumstances any great increase of produce by 400 lbs. compared with 200 lbs. of ammonia-salts could not be expected. Still, as the last column of the Table shows, the second increment of 200 lbs. did, under favourable conditions of mineral manuring, raise the produce by more than 4 bushels of grain, and by from $5\frac{1}{2}$ to $7\frac{1}{4}$ cwts. of straw; bringing it up, with superphosphate of lime, to $49\frac{5}{8}$ bushels of corn, and 34 cwts. of straw; and with superphosphate and the "mixed alkali-salts" together, to $50\frac{3}{4}$ bushels of corn, and $36\frac{3}{8}$ cwts. of straw.

There is proportionally much more increase of straw than of corn, especially when both the superphosphate and mixed alkali-salts were used. There is also a lower weight per bushel of dressed corn, and a much lower proportion of corn to straw, than with the corresponding mineral manures, either alone, or with the smaller quantity of ammonia-salts. It is clear, therefore, that the extra quantity of ammonia-salts considerably increased the luxuriance; but that the amount of plant produced was more than could, under the conditions of the seasons, form a fair proportion of corn, and ripen well.

Although the second increment of 200 lbs. of ammonia-salts, has thus not yielded anything like the same amount of increase as the first, in the seasons of the application, it will afterwards be seen (Section IV.) that there was a considerable residue of nitrogen left within the soil, which remained available for future crops through many succeeding seasons.

After the six years of the double application, the amount of ammonia-salts was reduced to 200 lbs. per acre per annum, and the experiment continued for ten consecutive seasons. From that time, however, an amount of nitrate of soda (275 lbs.) containing the same amount of nitrogen as 200 lbs. of ammonia-salts, was substituted for the latter; and the results obtained during the four years of the experiment which have so far elapsed, are given in Table XXXV. (next page.)

It is remarkable that the average produce is almost identical by the nitrate alone, and by the nitrate and "mixed alkali-salts" together. Though much higher, it is again almost identical by the nitrate and superphosphate, and by the nitrate, superphosphate, and "mixed alkali-salts." The little effect, hitherto, of the potass, soda, and magnesia-salts is here again illustrated. The last column shows that, over the four seasons in question, the nitrate gave, under each of the conditions of mineral manuring, both more corn and more straw than the corresponding amount of ammonia-salts. In what degree, however, this difference should be attributed to a greater effect of the nitrate, and in what to a still effective residue from the excessive supply of ammonia-salts

TABLE XXXV.—Average Annual Produce and Increase by 275 lbs. Nitrate of Soda per Acre per Annum, alone, and with Mineral Manures.

Four Years, 1868-1871.

Plots.	MANURES PER ACRE, PER ANNUM. 275 lbs. Nitrate of Soda, without Mineral Manure, and with Mineral Manures as under.	Average Annual Produce. 4 Years, 1868-'71.	AVERAGE ANNUAL INCREASE.		
			Over Mean Unmanured.	Over corresponding Mineral Manures.	Over corresponding Mineral Manures, and 200 lbs. Ammonia-salts.

Dressed Corn per Acre—Bushels.

1 AA	Without Mineral Manure	32	16½	16½	3½
2 AA	Superphosphate of Lime	46½	30½	26½	3½
3 AA	"Mixed Alkali-salts"	32½	16½	15½	½
4 AA	Superphos. and Mixed Alkali-salts	46½	30½	25½	4½

Total Corn per Acre—lbs.

1 AA	Without Mineral Manure	1788	903	929	187
2 AA	Superphosphate of Lime	2691	1806	1577	187
3 AA	"Mixed Alkali-salts"	1852	967	858	11
4 AA	Superphos. and Mixed Alkali-salts	2692	1807	1498	244

Straw (and Chaff) per Acre—Cwts.

1 AA	Without Mineral Manure	20½	9½	10	3½
2 AA	Superphosphate of Lime	28½	17½	18½	3½
3 AA	"Mixed Alkali-salts"	21½	11	11½	2½
4 AA	Superphos. and Mixed Alkali-salts	28½	18½	17	2

Total Produce (Corn, Straw, and Chaff) per Acre—lbs.

1 AA	Without Mineral Manure	4047	2023	2061	596
2 AA	Superphosphate of Lime	5843	3819	3611	614
3 AA	"Mixed Alkali-salts"	4233	2214	2142	268
4 AA	Superphos. and Mixed Alkali-salts	5901	3877	3411	475

Weight per Bushel of Dressed Corn—lbs.

1 AA	Without Mineral Manure	53·9	0·1	0·3	-0·1
2 AA	Superphosphate of Lime	56·4	2·6	1·5	0·5
3 AA	"Mixed Alkali-salts"	54·4	0·6	-0·6	-0·8
4 AA	Superphos. and Mixed Alkali-salts	56·6	2·8	1·3	-0·1

Corn to 100 Straw.

1 AA	Without Mineral Manure	80·6	0·8	1·6	-7·7
2 AA	Superphosphate of Lime	87·9	8·1	-12·5	-7·4
3 AA	"Mixed Alkali-salts"	78·4	-1·4	-11·9	-9·6
4 AA	Superphos. and Mixed Alkali-salts	89·5	9·7	-3·1	4·5

during the first 6 years, it is not possible to determine. Further comments on the results at present would, therefore, be premature.

It will be more instructive to compare the results obtained by the mixture of mineral and nitrogenous manure on wheat and on barley respectively. The first comparison will be between the effects of the same amounts of superphosphate of lime, and sulphates of potass, soda, and magnesia, and 200 lbs. of ammonia per acre per annum, for 20 consecutive seasons, with each crop. Table XXXVI. shows the result; and as in other cases the produce per acre, and not the increase, is taken for illustration.

TABLE XXXVI.—Average Annual Produce of Wheat and of Barley by Mixed Mineral Manure, and 200 lbs. Ammonia-salts per Acre per Annum.

MANURES PER ACRE, PER ANNUM:— 3½ cwts. Superphosphate of Lime. 200 lbs. (1) Sulphate of Potass. 100 lbs. (2) Sulphate of Soda. 100 lbs. Sulphate of Magnesia. 200 lbs. Ammonia-salts.	AVERAGE ANNUAL PRODUCE, &c.			
	First 10 Years, 1852-'61.	Second 10 Years, 1862-'71.	Total Period, 20 Years, 1852-'71.	Second 10 Years over (or under—) First 10.
Total Corn, per Acre.				
Wheat (Plot 6), 20 years, 1852-1871	lbs. 1697	lbs. 1639	lbs. 1668	Per Cent. — 3·4
Barley (Plot 4 A), 20 years, 1852-1871	2593	2668	2630	2·9
Barley over (or under —) wheat	896	1029	962	
Straw (and Chaff), per Acre.				
Wheat (Plot 6), 20 years, 1852-1871	2946	2554	2750	— 13·3
Barley (Plot 4 A), 20 years, 1852-1871	3234	3139	3187	— 2·9
Barley over (or under —) wheat	288	585	437	
Total Produce (Corn, Straw, and Chaff), per Acre.				
Wheat (Plot 6), 20 years, 1852-1871	4643	4193	4418	— 9·7
Barley (Plot 4 A), 20 years, 1852-1871	5827	5808	5817	— 0·3
Barley over (or under —) wheat	1184	1615	1399	

(1) 300 lbs. the first 7 years of wheat, and 6 years of barley; 200 lbs. afterwards.

(2) 200 lbs. the first 7 years of wheat, and 6 years of barley; 100 lbs. afterwards.

For the period of 20 years included in the comparison, the manuring was, with a quite immaterial exception explained in the foot-notes, identical for the two crops. But whilst in the case of the barley, the period commences with the first year of

the experiments, in that of the wheat 8 experimental crops had already been taken. During that period, however, large quantities of superphosphate of lime, and potass, soda, and magnesia-salts had been applied, as well as liberal dressings of ammonia-salts. It would hardly be concluded, therefore, that the plot had suffered in wheat-growing condition by its previous treatment. Still, though the quantity of wheat-grain averages nearly the same over the two periods, that of the straw and total produce falls off considerably during the latter half of the 20 years. On the other hand, with the barley the quantity of corn is slightly higher, that of straw slightly lower, and that of total produce almost identical, over the two halves of the total period.

It is possible, therefore, that the previous history of the plots may be somewhat to the detriment of the results with wheat; but it is not probable that it has had much adverse influence.

Taking the results as they stand, the barley gives, with exactly the same manure over 20 years, an average annual produce of more than one-half more corn, more than one-sixth more straw, and about 1400 lbs. more total produce (corn and straw together) than the wheat. If, instead of the acreage produce, the increase over that by the same mineral manures without ammonia be taken, the general result is the same; namely, a great deficiency of corn, of straw, and of total produce, of wheat compared with barley, by the same manuring. How is this to be explained?

In reference to this point attention may here be recalled to the facts—that whilst the wheat is autumn-sown and autumn-manured, the barley is both spring-sown and spring-manured; and that when ammonia-salts are sown in the autumn, the winter drainage carries with it large amounts of the nitrogen of the ammonia-salts in the form of nitrates. The probable extent of the loss that may thus arise, will be considered in Section IV. It must suffice here, therefore, to state in general terms that existing evidence leads to the conclusion that it may be very considerable.

The difference of result obtained with wheat and with barley is again illustrated, under somewhat different conditions, in Table XXXVII. (see next page). The comparison is between the effects of the "mixed mineral manure" and 400 lbs. of ammonia-salts, annually applied to the two crops. For wheat the produce is averaged over 20 years (1852-'71) of the treatment, and also over the first 6 years only, those being the seasons in which the same experiment was made with the barley.

In all previous comparisons between wheat and barley the quantity of *produce per acre* has been taken, and not the *increase* of produce over that without manure, or, as the case may be, the increase by mineral manure and ammonia-salts over that by mineral manure without ammonia. It has, however, been re-

marked that, although the figures would be different, the general result would be the same, whether produce or increase were compared. It would not be so in the case of the experiments now under consideration. Hence, the Table has been arranged to show the comparison, both between the produce per acre, and the increase of produce by the mineral manure and 400 lbs. of ammonia-salts, over that by the corresponding mineral manure alone.

TABLE XXXVII.—Average Annual Produce and Increase of Wheat and of Barley by Mixed Mineral Manure, and 400 lbs. Ammonia-salts per Acre per Annum.

MANURES PER ACRE, PER ANNUM— 34 Cwts. Superphosphate of Lime. 300 lbs. (1) Sulphate of Potass. 200 lbs. (2) Sulphate of Soda. 100 lbs. Sulphate of Magnesia. 400 lbs. Ammonia-salts.	AVERAGE ANNUAL PRODUCE PER ACRE.		Mineral Manure and Ammonia- salts over Mineral alone.	Barley over (or under —) Wheat.	
	Mineral Manure and 400 lbs. Ammonia- salts.	Mineral Manure alone.		Produce.	Increase.
Total Corn, per Acre.					
Wheat (Plot 7), 20 years, 1852-1871 ..	lbs. 2228	lbs. 1068	lbs. 1160	lbs.	lbs.
Wheat (Plot 7), 6 years, 1852-1857 ..	2195	1171	1024	606	— 137
Barley (Plot 4 AA), 6 years, 1852-1857	2801	1914	887		
Straw (and Chaff), per Acre.					
Wheat (Plot 7), 20 years, 1852-1871 ..	3959	1678	2281		
Wheat (Plot 7), 6 years, 1852-1857 ..	4233	2012	2221	— 160	— 160
Barley (Plot 4 AA), 6 years, 1852-1857	4073	2012	2061		
Total Produce (Corn, Straw, and Chaff), per Acre.					
Wheat (Plot 7), 20 years, 1852-1871 ..	6187	2746	3441		
Wheat (Plot 7), 6 years, 1852-1857 ..	6428	3183	3245	446	— 297
Barley (Plot 4 AA), 6 years, 1852-1857	6874	3926	2948		

(1) Only 200 lbs. after the first 7 years of wheat, and 6 of barley.

(2) Only 100 lbs. after the first 7 years of wheat, and 6 of barley.

Before directing attention to the results themselves, it should be premised that, as in the last experiments quoted, the wheat plot had grown 8 crops, liberally dressed with artificial manures, prior to the period to which the figures refer; but the results with barley commence with the first year of the experiments, and the application of 400 lbs. of ammonia-salts to that crop was only continued for the 6 years referred to. To the wheat, however, the application has been continued up to the present time; and, over 20 years, it has yielded an average of more corn, though less

straw and total produce, than over the first 6 years. It would be concluded, therefore, that the wheat plot was not unduly exhausted at the commencement; and that the comparison between the two crops over the first 6 years would, probably, be but little open to objection on the score of difference in previous condition of the land.

Taking first the *produce per acre* of the two crops, there is, as with the smaller quantity of ammonia-salts, considerably more barley-grain than wheat-grain; but, on the other hand, less barley straw; and an annual average of only 446 lbs. more total produce (corn and straw) of barley than of wheat, instead of nearly 1400 lbs., as when the smaller quantity of ammonia-salts was employed. This difference of result is doubtless due to the proportionally much less increase of barley for a given amount of ammonia in manure with the larger than with the smaller supply of ammonia-salts. The probability is that, in the case of the autumn-sowing for the wheat, the distribution, the state of combination, and the loss by drainage are such, that the quantity of the supplied nitrogen remaining available within a given range of soil when active growth commences in the spring is not excessive, and does not induce over luxuriance; whereas, the same amount applied in the spring for the barley, being less subject to either rapid distribution or drainage, induces too much luxuriance, and, consequently, leads to the laying of the crop, and to reduced eventual productiveness.

The less difference between the produce of wheat and of barley when the larger quantity of ammonia-salts is applied, is, therefore, due, in great measure, to a proportionally less effect on the barley. Nevertheless, the fact of a less amount of produce per acre from a given amount of mineral manure and ammonia-salts applied in the autumn for wheat, than from the same amount applied in the spring for barley, is again clearly illustrated.

If, however, the *increase* of produce with ammonia over that without it be taken as the basis of illustration, the result is different. Thus, instead of an annual average of 446 lbs. more total produce (corn and straw together) of barley than of wheat, there is of *increase* of produce by the mineral manure and 400 lbs. of ammonia-salts over that by the mineral manure alone, less in the case of the barley than of the wheat. The average annual deficiency is 137 lbs. of corn, and 160 lbs. of straw, or 297 lbs. of total produce (corn and straw together). This difference is accounted for by the fact that there is an average of 743 lbs. more total produce of barley than of wheat by the mineral manure alone; there is, therefore, so much more to be deducted from the produce by the mineral manure and the ammonia-salts

together; leaving, of course, so much less to be reckoned as increase due to the action of the ammonia-salts.

Reference has already been made to the probable or possible cause of the much greater produce of barley than of wheat by the mineral manure alone (p. 93). On this point it should be borne in mind that, for the wheat the mineral manures, as well as the ammonia-salts, are applied in the autumn, whereas for the barley both are applied in the spring. It is a question, therefore, whether there be not a much greater dilution and distribution of the autumn-sown mineral manures by the winter rains; a locking-up of some of their constituents in difficultly soluble combinations within the soil; hence a less active root-development in the upper and more highly nitrogenous layers of the soil when growth commences in the spring; and hence, also, less luxuriance in the case of the wheat; but, on the other hand, a more rapid exhaustion of the previously accumulated nitrogen within the soil by the barley. If this be so, the higher produce of barley than of wheat by mineral manures alone is, in a sense, accidental, and may prove not to be permanent. In that case, the comparison of the actual *produce* will more fairly illustrate the difference of effect of the mineral manure and a given amount of ammonia-salts applied to wheat and to barley, than will that of the mere *increase* over the produce by the mineral manure alone; and the less amount of increase of barley than of wheat so calculated in these last experiments, will prove no exception to the conclusion arrived at from the results of the other experiments, namely, that a given amount of ammonia-salts applied in the spring for barley is more productive than an equal amount applied in the autumn for wheat.

Briefly enumerated, the very important results, obtained by the use of nitrogenous and mineral manures together, are—that much more than the average barley crop of the country has been obtained for 20 years in succession on the same land, by the annual application, in the spring, of 200 lbs. of ammonia-salts, and 3½ cwt. superphosphate of lime; that the addition of salts of potash, soda, and magnesia, gave no further increase; and that the application, for the same period, of the same amount of ammonia-salts (with mineral manure) in the autumn, for wheat, gave nearly 37 per cent. less corn, nearly 14 per cent. less straw, and about 24 per cent. less total produce. The causes of the remarkable differences of result with wheat and with barley will be considered in Section IV.

Average annual produce and increase by Rape-cake.

Rape-cake is estimated to contain, on the average, about 4·75 per cent. of nitrogen. It also contains a large amount of carbonaceous organic substance, and about 8 per cent. of mineral matter. It has been applied on 4 plots each year; on one alone, on one with superphosphate, on one with the "mixed alkali-salts," and on one with both superphosphate and the mixed alkali-salts. For the first 6 years 2000 lbs. = 95 lbs. nitrogen, were applied per acre per annum; but during the next 14 years only 1000 lbs. = 47·5 lbs. nitrogen. Table XXXVIII. (p. 112) shows the produce over the first 6 years with the larger amount, over the last 14 years with the smaller amount, and both produce and increase over the whole 20 years.

It is first to be observed that where the rape-cake is used without superphosphate, Plots 1 and 3, there is much less deficiency of produce, both corn and straw, compared with Plots 2 and 4 with superphosphate, than in the experiments with ammonia-salts without, compared with those with, superphosphate. The fact is that the rape-cake itself supplies some phosphates; so that superphosphate has less effect when added to it than to ammonia-salts. The general result is, that the rape-cake alone, and the rape-cake and mixed alkali-salts, yield considerably more of both corn and straw than ammonia-salts alone, or ammonia-salts and mixed alkali-salts; but, where used with superphosphate, there is more produce of both corn and straw from a less amount of nitrogen supplied as ammonia-salts, or nitrate of soda, than from a larger quantity in rape-cake.

Thus, over the first 6 years, rape-cake in amount supplying 95 lbs. of nitrogen per acre per annum was applied, and over the same period ammonia-salts = 82 lbs. of nitrogen. But where each was used with superphosphate, whether without or with the addition of the mixed alkali-salts, there was more produce of both corn and straw by the ammonia-salts than by the rape-cake. In fact, there was not much less barley-grain, though a greater deficiency of straw, with superphosphate and ammonia-salts = only 41 lbs. of nitrogen, than with superphosphate and rape-cake = 95 lbs. of nitrogen.

Over the next 14 years the application of rape-cake was reduced to 1000 lbs. per acre per annum = 47·5 lbs. nitrogen; and where ammonia-salts = 82 lbs. nitrogen had previously been applied, the quantity was also reduced to one-half = 41 lbs. nitrogen. The result in each case was that, with superphosphate and the reduced amount of nitrogenous manure, there was an average annual produce of about as much corn, though less

TABLE XXXVIII.—Average Annual Produce and Increase by Rape-cake

Plots.	MANURES PER ACRE, PER ANNUM.	AVERAGE ANNUAL PRODUCE, &c.				AT- TEND- ANCE
	2000 lbs. Rape-cake, 6 yrs., 1852-'57. 1000 lbs. Rape-cake, 14 yrs., 1858-'71. Without Mineral Manure, and with Mineral Manures as under.	First Period, 6 Years, 1852-'57.	Second Period, 14 Years, 1858-'71.	Total Period, 20 Years, 1852-'71.	Second Period, over (or under —) First.	(or less than 1852-'57.)
Dressed Corn, per Acre—Bushels.						
1 C	Without Mineral Manure ..	48½	44	45½	— 8·8	24
2 C	Superphosphate of Lime ..	47½	46½	46½	— 2·6	25
3 C	Mixed Alkali-salts	44½	43½	43½	— 2·8	24
4 C	{Superphosphate and Mixed Alkali-salts}	48	47½	47½	— 1·8	24
Total Corn, per Acre—lbs.						
1 C	Without Mineral Manure ..	2664	2527	2568	— 5·1	130
2 C	Superphosphate of Lime ..	2673	2660	2664	— 0·5	147
3 C	Mixed Alkali-salts	2505	2489	2494	— 0·6	136
4 C	{Superphosphate and Mixed Alkali-salts}	2662	2713	2698	1·9	151
Straw (and Chaff), per Acre—Cwts.						
1 C	Without Mineral Manure ..	31½	24½	26½	— 21·9	14
2 C	Superphosphate of Lime ..	32½	26½	28½	— 17·8	16
3 C	Mixed Alkali-salts	30½	25½	27½	— 15·0	15
4 C	{Superphosphate and Mixed Alkali-salts}	32½	28½	29½	— 13·1	17
Total Produce (Corn Straw, and Chaff), per Acre—lbs.						
1 C	Without Mineral Manure ..	6212	5296	5571	— 14·7	305
2 C	Superphosphate of Lime ..	6305	5646	5844	— 10·5	332
3 C	Mixed Alkali-salts	5895	5369	5527	— 8·9	295
4 C	{Superphosphate and Mixed Alkali-salts}	6300	5875	6002	— 6·7	340
Weight per Bushel of Dressed Corn—lbs.						
1 C	Without Mineral Manure ..	51·0	55·0	53·8	7·8	1·4
2 C	Superphosphate of Lime ..	51·2	55·0	53·9	7·4	1·3
3 C	Mixed Alkali-salts	51·1	54·9	53·7	7·4	1·3
4 C	{Superphosphate and Mixed Alkali-salts}	50·7	54·9	53·6	8·3	1·2
Corn to 100 Straw.						
1 C	Without Mineral Manure ..	75·4	92·4	87·3	22·5	—0·8
2 C	Superphosphate of Lime ..	74·1	90·5	85·6	22·1	—2·3
3 C	Mixed Alkali-salts	74·2	87·5	83·5	17·9	—4·6
4 C	{Superphosphate and Mixed Alkali-salts}	73·8	87·2	83·0	19·0	—5·1

straw, than with the previous too heavy dressings. There was, moreover, not only more corn and more straw by the superphosphate and the reduced amount of ammonia-salts, but also more where ammonia-salts = only 41 lbs. of nitrogen had been used from the commencement, than by the superphosphate and the rape-cake.

The nitrogen of the nitrogenous organic matter of the rape-cake would doubtless be much less rapidly available than that supplied in ammonia-salts; and analysis of the soil has shown that the rape-cake has left a considerable residue of nitrogen near the surface; nor can there be any doubt that, since the excessive dressings of both ammonia-salts and rape-cake have been stopped, there has annually been some effect due to the unexhausted residue of nitrogen previously applied.

The general result is, that about 9 cwt. of rape-cake per acre per annum have given a produce exceeding the average crop of the country, but not quite a maximum yield for the soil and seasons in question. The mineral constituents of the rape-cake doubtless serve to render effective the nitrogen associated with them; though there can be little doubt that the increase yielded is mainly dependent on the amount of nitrogen rendered available by the decomposition of the nitrogenous organic matter of the rape-cake. But since the effect is less for a given quantity of nitrogen supplied, than when ammonia-salts or nitrate of soda is used, it is impossible to decide absolutely whether, or in what degree, the carbonaceous organic matter has been of service. It would yield by decomposition carbonic acid and other products. The increased supply of carbonic acid in the soil would, it must be concluded, not only serve as a source of carbon, but aid the solution and distribution of other plant-food, and so far further growth. But that any such supply is essential for the successful growth of either wheat or barley is clearly disproved by the fact that maximum crops of both have been grown for 20 years or more by means of mineral manures and ammonia-salts, without any return to the soil of carbonaceous organic matter. The carbonaceous organic matter of farmyard manure is obviously equally unessential, so far as the successful growth of the cereals is concerned.

Summary of the Results obtained on the Growth of Barley for 20 Years in succession on the same land, without Manure, and by different descriptions of Manure.

1. Without manure, the average annual produce of barley over 20 years was about 21 bushels of dressed corn, and 12 cwt. of straw. The quality, indicated by the weight per bushel of grain,

was higher over the second than over the first 10 years; but the quantity, of both corn and straw, was between 23 and 24 per cent. less over the second 10 years.

2. Compared with wheat grown for many years in succession without manure, barley gave an average of more corn, less straw, and nearly the same weight of gross produce (corn and straw together); but the barley fell off more in produce of grain, and about equally in straw, over the later years.

3. Farmyard manure applied every year for 20 years, gave an average annual produce of more than 48 bushels of barley-grain, and 28 cwts. of straw. The weight per bushel, quantity of grain, and quantity of straw, were all considerably higher over the second than over the first 10 years. The manure probably supplied from three to four times as much nitrogen as any of the artificial manures, and much more of carbonaceous organic matter, and of every other constituent of the crop, than was contained in the produce. It would leave a large residue of nitrogenous, carbonaceous, and other matters in the soil, which seem to be very slowly available for future crops; but the large accumulation of organic matter increases the porosity of the soil, and its capacity for the retention of moisture; and the crops are thereby rendered both less susceptible to injury from excess of rain, and more independent of drought.

4. As without manure, so with farmyard manure, barley, compared with wheat, yielded, over a series of years, more corn, less straw, but nearly the same quantity of total produce (corn and straw together). This is remarkable, when it is considered that the wheat is autumn-sown and autumn-manured, and the barley spring-sown and spring-manured.

5. Mineral manures alone gave very poor crops, and the quantity of both corn and straw fell off considerably during the later years; but superphosphate of lime alone gave more than salts of potass, soda and magnesia, and not much less than the mixture of all. It may be concluded that the soil was not relatively deficient in any of the mineral constituents which the manures supplied; and, from the falling off in the produce both without manure and with purely mineral manures, it is probable that the growth of the crop under such conditions is gradually exhausting the available nitrogen accumulated within the soil from previous cultivation, manuring, and cropping.

6. Over the same period of 20 years, a mixed mineral manure, containing salts of potass, soda and magnesia, and superphosphate of lime, gave, of barley, much more grain, rather less straw, but considerably more total produce, than of wheat. It is probable that, with the autumn-manuring for the wheat, the various constituents are distributed by the rains, or enter into

less soluble combinations, or both, during the winter; that hence there is less active root-development in the upper and more highly nitrogenous layers of the soil in the spring, and that hence the barley is more rapidly exhausting the accumulated nitrogen of the surface-soil than the wheat.

7. By nitrogenous manures alone (ammonia-salts or nitrate of soda) much more barley was obtained than by mineral manures alone; the produce declined much less in the later years; and, for 20 years in succession, even fair, though not large, crops were obtained. This result is a striking illustration of the mineral resources of such a soil; and it shows that when in what may, in an agricultural sense, be called a corn-exhausted condition, it was deficient in available nitrogen relatively to available mineral constituents.

8. By ammonia-salts and superphosphate of lime together, an average produce of more than 47 bushels of dressed corn, and more than 28½ cwt. of straw, or considerably more than the average barley crop of the country, was obtained over 20 years in succession; and the produce of corn increased, and that of straw in a less degree diminished, giving a higher total produce, during the later than the earlier years. Notwithstanding the great demand made upon the supplies of potass within the soil, by the growth of the crop for so many years by ammonia-salts and superphosphate without potass, the addition of salts of potass, soda and magnesia, gave no further increase of corn, and very little of straw and total produce. The potass-yielding capabilities of such a soil, and the beneficial effects of the use of superphosphate, with nitrogenous manures, for spring-sown corn crops, are here strikingly illustrated.

9. When the same mixed mineral manure, and 200 lbs. of ammonia-salts, were applied per acre per annum for 20 years, in the autumn for wheat, and in the spring for barley, the barley gave more than one-half more corn, nearly one-sixth more straw, and nearly one-third more total produce, than the wheat. When the same mineral manure was used with a larger quantity of ammonia-salts, the result was still in favour of the barley, but in a less degree than with the smaller amount.

10. After applying 400 lbs. of ammonia-salts per acre per annum to barley for 6 years, and then reducing the amount to 200 lbs., the plots so treated gave, for 10 years in succession, more produce than those which had only received 200 lbs. annually from the commencement. It thus appears that the excessive supply of 400 lbs. had left a residue of nitrogen within the soil which was available for succeeding crops.

11. The experiments on barley with nitrate of soda and ammonia-salts respectively, are not exactly comparable with one

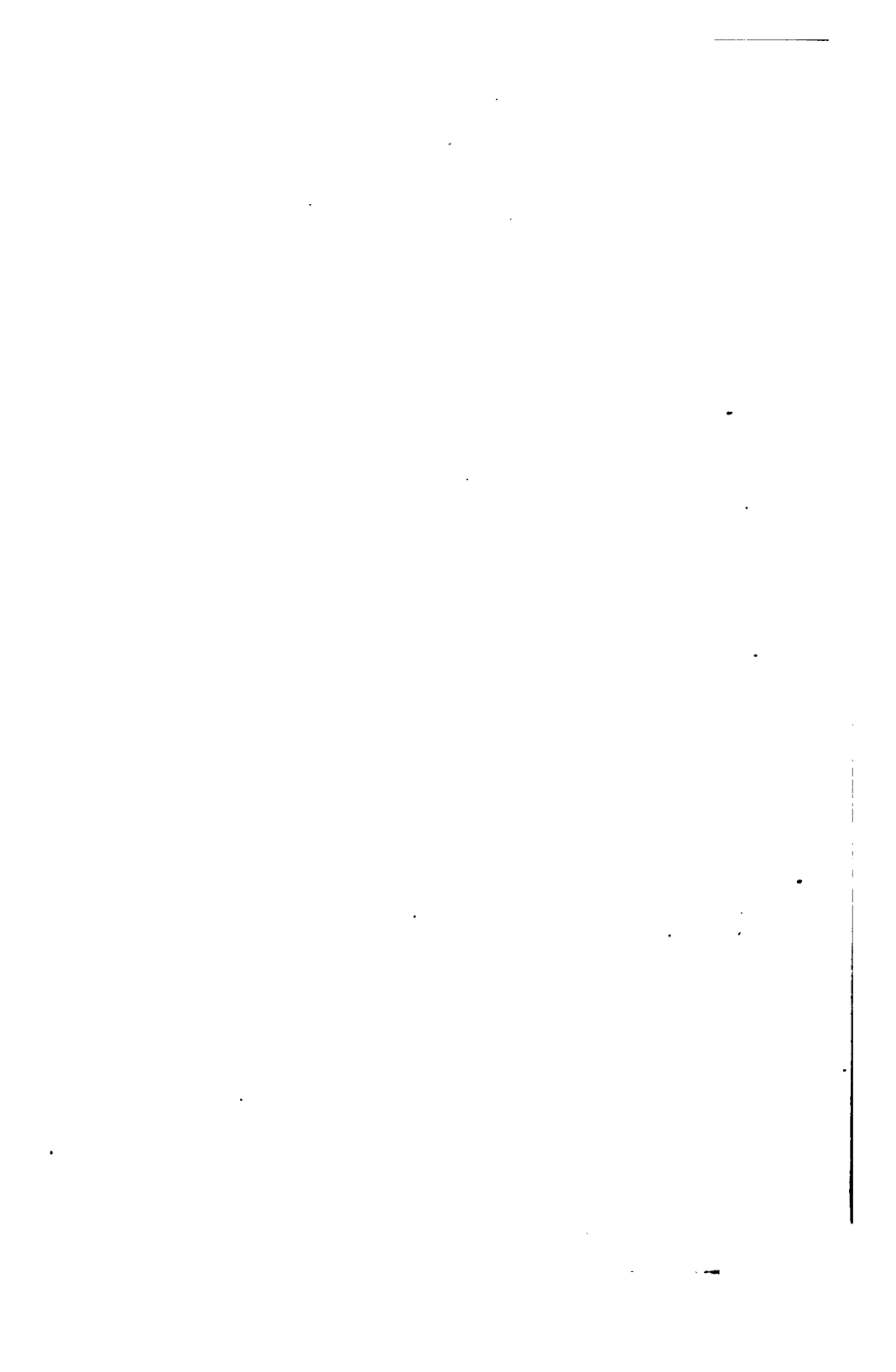
another; but, so far as can be judged, a given amount of nitrogen as nitrate of soda has yielded more produce than the same amount as ammonia-salts, and especially so in dry seasons. This is probably due to the greater solubility of the nitrate, or its products of decomposition, to their action on the subsoil, disintegrating it, and rendering it more porous; thus affording more surface for the absorption and retention of moisture and manure, and greater permeability to the roots, rendering the plants less dependent on the fall of rain during growth.

12. By the annual application of rape-cake, whether without or with the addition of mineral manures, more barley than the average crop of the country has been obtained; but, in proportion to the nitrogen it contained, less than by ammonia-salts or nitrate of soda. The mineral constituents of the rape-cake no doubt aid in rendering effective the nitrogen associated with them, though its effects are doubtless mainly dependent on the amount of nitrogen rendered available by the decomposition of its nitrogenous organic matter; but the nitrogen of such matter is much less rapidly available than that of ammonia-salts or nitrates.

13. Over 20 years or more, in succession, ammonia-salts, or nitrate of soda, with mineral manure (without silica), have yielded considerably more of both wheat and barley than the average crops of the country, and more also than either farmyard manure or rape-cake. It is obvious, therefore, that the return to the soil of carbonaceous organic matter as manure is unessential, so far as the successful growth of either of these crops is concerned.

SECTION III.—AMOUNT OF AMMONIA IN MANURE (OR ITS EQUIVALENT OF NITROGEN IN OTHER FORMS) REQUIRED TO YIELD A GIVEN INCREASE OF GRAIN (AND ITS PROPORTION OF STRAW).

Comparison of the produce obtained by the different manures has shown—that carbonaceous organic matter, supplied so largely in farmyard manure and rape-cake, is at any rate not essential as manure for either wheat or barley; that mineral manures alone will not yield fair crops of either; that nitrogenous manures give much more produce than mineral manures alone; and that the mixture of nitrogenous and mineral manures will give full crops for many years in succession. In other words—the supply by manure of matter yielding by decomposition carbonic acid, and other carbon compounds, within the soil, has little or no effect; mineral manures alone will not enable the growing plant to obtain sufficient nitrogen from the soil or the atmosphere;



ant

1 SU

EST

186

acre

lbs

3.2

1.5

3.6

1.8

2.1

2.4

nitrogen in an available form was liberally provided, the and constituents of the soil were insufficient for its full effect ; STUD when so supplied, the mineral manures, which alone had little greatly increased the efficacy of the supplied nitrogen.

The general result is, that whilst it is essential that there be a provision of mineral constituents, the amount of produce is more dependent on the supply of *available nitrogen within* than of any other constituent. The practical questions arise—How much ammonia, or of its equivalent of nitrogen in some other form, will, on the average, be required to a given amount of increase of barley-grain, and its average ration of straw? and how much will the quantity vary, relating to the amount applied per acre, to the supply of mineral constituents, and to the characters of the seasons?

1. The folding Table XXXIX. (facing this page) shows the
2. amount of ammonia—or of nitrogen in nitrate of soda, or rape-
3. seed or farmyard manure, reckoned as ammonia—required to
4. — 1 bushel (52 lbs.) of increase of barley-grain, and its pro-
5. — portion of straw, under a great variety of conditions of manuring,
6. — in each of the 20 seasons. In each case the increase is calcu-
7. — lated over the produce on the corresponding plot without nitro-
8. — genous manure; that is, 1 A, 1 AA, 1 AAS, 1 C, over 1 O ;
9. — &c., over 2 O ; and so on ; 1 N, and 2 N (with nitrate of
10. — soda), and 7 (with farmyard manure), are taken over the mean
11. — manured produce (1 O and 6-1). The average result for
12. — different periods, or series of years, is also given. Where there
13. — has been no change of manure, the averages are, as a rule, calcu-
14. — lated for the first half, the second half, and the total period ; and
15. — where there has been any change, for the periods so indicated ;
16. — but, for the sake of comparison, for corresponding periods in
17. — other cases.

The five plots receiving 200 lbs. of ammonia-salts per acre annum for 20 years are classed in the Table as Series I. Of these, Plot 1 A has had the ammonia-salts without any mineral manure; 2 A with superphosphate; 3 A with sulphates of potass, soda, and magnesia; 4 A with superphosphate and sulphates of potass, soda, and magnesia; and 5 A with superphosphate and sulphate of potass. Taking the average for the 20 years in each case, the quantity of ammonia required to produce 1 bushel increase of barley, and its proportion of straw, is on the three plots with superphosphate 2·13, 2·41, and 2·10 lbs.; on the plot with salts of potass, soda, and magnesia, without superphosphate, 3·59 lbs.; and on the one without any mineral manure at all 3·68 lbs.

Thus, taking the mean of the three experiments with superphosphate, the amount of ammonia required is rather under $2\frac{1}{2}$ lbs.;

but with the mixed alkali-salts without superphosphate, and without any mineral manure at all, it is between $3\frac{1}{2}$ and $3\frac{3}{4}$ lbs. That is to say, a given amount of ammonia-salts was more than one-and-a-half-time as effective when there was a liberal provision of mineral constituents, but especially of phosphates, within the reach of the roots, than when there was not.

Assuming that, with otherwise favourable soil-conditions, and with an application of not more than 50 lbs. of ammonia per acre, an increase of 1 bushel of barley (52 lbs.), and its straw, may, on the average of seasons, be obtained for every 2 to $2\frac{1}{4}$ lbs. of ammonia applied, still, it is seen that the amount may vary very greatly according to the characters of the seasons. Thus, on Plot 2 A, with superphosphate, only about $1\frac{1}{4}$ lb. was required in the favourable seasons of 1863 and 1869, but in the bad seasons of 1853 and 1856, 5.36 and 4.48 lbs. respectively, were required.

These great differences according to season occurred, it should be remembered, when only a moderate amount of ammonia-salts was used, and when it was employed under favourable conditions as to mineral manures. But even with the same moderate application, but at the same time less favourable soil-conditions, that is without superphosphate, or without any mineral manure, the differences in the amount required to yield a given increase of produce are very much greater. Thus, when the same quantity of ammonia-salts is used without any mineral manure (Plot 1 A), there is a variation in the amount of ammonia required to yield 1 bushel of increase from 18.05 lbs. in 1859, to 2.25 lbs. in 1871; and when with salts of potass, soda, and magnesia, but without superphosphate (Plot 3 A), from 24.75 lbs. in 1859, to 2.18 lbs. in 1863. In fact, in 1859, there was scarcely any increase at all by ammonia-salts when not accompanied by phosphates; and reference to the characters of the season, and of the growth (pp. 30-32), will show that there was probably defective root-development; a condition under which any deficiency of phosphates within a limited range of soil would very unfavourably affect the characters of growth.

Lastly in regard to Series I:—Under each of the five conditions as to mineral manuring, the amount of ammonia required to produce a given increase of grain was very much less over the second than the first 10 years. It has already been shown that the last 10 seasons were the more favourable for the production of corn, and more especially so where superphosphate was used. But, as there was a greater falling off over the later years where the mineral manures were used alone, the further amount of produce obtained where the mineral manures and ammonia-salts were used together, which is reckoned as increase due

to ammonia, was proportionally higher over the last ten years, than was the increase in the actual produce of corn per acre. Further, the actual produce of straw per acre was uniformly, and that of the total produce (corn and straw), taking the average of the plots, rather lower, over the last ten years. That the total produce was lower rather than higher over the later years, seems to afford evidence that, with this smaller dressing of ammonia-salts, there was little or no effect in succeeding, from accumulation in preceding years.

When, as in Series II., double the quantity, or 400 lbs. ammonia-salts, was applied per acre per annum for the first six years, the average amount of ammonia required to yield 1 bushel of increase was, according to the same mode of calculation, without mineral manure, 4.81 lbs.; with superphosphate, 5.06 lbs.; with mixed alkali-salts 6.38 lbs.; and with superphosphate and mixed alkali-salts, 5.86 lbs. Thus, the amount required appears to be less without, than with either of the mineral manures, less with superphosphate than with superphosphate and mixed alkali-salts, and less with the latter than with mixed alkali-salts without superphosphate. The apparently more favourable result without than with mineral manure, is explained by the fact, that the increase by ammonia-salts is, in each case, calculated over the produce by the corresponding unmanured or mineral-manured produce, as the case may be; and as the produce by mineral manures, especially if containing phosphates, was so much higher than that without manure, there is so much more to deduct from the produce with ammonia-salts in addition; and hence, though the produce by the ammonia-salts with mineral manure is much higher, the increase so reckoned as due to the ammonia only is less.

During the next ten years, the quantity of ammonia-salts was reduced from 400 lbs. to 200 lbs.; and during the last four years the ammonia-salts were replaced by 275 lbs. of nitrate of soda, estimated to contain the same amount of nitrogen as 200 lbs. ammonia-salts, namely 41 lbs. = 50 lbs. ammonia. Over both of these periods the result is much more favourable with each of the four conditions as to mineral manure than during the first six years, and also relatively much more so where the superphosphate was employed. This depends in part on the fact that, whilst the produce without manure or by the mineral manures alone, which is the standard over which the increase by ammonia is calculated, declined perceptibly from year to year, that where ammonia was used either did not decline at all, or did so much less rapidly; and hence the increase calculated as due to the ammonia (or nitrogen reckoned as ammonia) is higher.

In reference to these results it should further be observed, that

since there is evidence that the excessive supply of ammonia-salts during the first six years left a residue of nitrogen which was effective for ten, if not more, years afterwards, not only do the figures for the first six years understate the total or final effect of the ammonia applied during that period, but those for the subsequent years overstate the result for those years. The average columns of the Table give, however, not the mere arithmetical means of the results for the individual years, but the direct averages for the periods; and the result over the twenty years is, that, instead of only 2.13 lbs. of ammonia required when superphosphate and only 200 lbs. of ammonia-salts were used, there were 2.49 lbs. required when, for the first 6 of the 20 years, 400 lbs., for the next 10 years 200 lbs., ammonia-salts, and for the last 4 years 275 lbs. nitrate of soda, were applied. There is also a considerably less favourable result without than with the superphosphate. Lastly, as in the experiments with the smaller quantity of ammonia-salts every year, the variation of result according to season is very considerable; but, owing to the excess of ammonia applied in the early years, and to the effects of the accumulation afterwards, the exact figures for the individual years cannot be taken in illustration of the point.

During the last eight years of the twenty, one-half of the plots of Series II. received, besides the same manures as the other half, 400 lbs. of silicate of soda, per acre, per annum. The four portions so treated are respectively designated 1 AAS, 2 AAS, &c.; and the results are recorded in the Table under the heading of Series III. Almost every year it was quite obvious to the eye that there was a marked effect from the silicate on Plots 1 and 3, that is where no superphosphate was used; but comparatively little, if any, on Plots 2 and 4 with superphosphate. So striking was this result, that the silicate was examined in the laboratory to ascertain whether it contained any phosphate. It was found not to contain any; nor did it contain nitrate or nitrogen in any other form. Perhaps the most probable supposition is, that by the action of the alkaline silicate on the soil, otherwise locked up phosphoric acid was rendered available for the plants. It is possible, however, that, when the superphosphate was used, a secondary result of its action within the soil was the liberation of silicates, which, without it, were not available in sufficient quantity; and hence the little effect of the direct supply of silicates where the superphosphate was used, and the marked effect where it was not employed. Or, is it that when the acid-phosphate and alkaline silicate are mixed together, they are rendered comparatively insoluble and inactive? The result may perhaps be due in part to more than one of these actions.

Whatever may be the explanation of the fact, the Table shows

that there was, in almost every year of the eight, comparatively little difference in the amount of ammonia required to yield a bushel of increase of barley on Plots 2 and 4 of Series II. with superphosphate but without the silicate, and on Plots 2 and 4 of Series III. with superphosphate and with silicate. On the other hand, on Plots 1 and 3 of Series III., without superphosphate, but with silicate, the amount of ammonia required for a given effect was much less than on the corresponding plots of Series II. without the silicate. There was also a greater increase of straw by the use of the silicates where superphosphate was not, than where it was employed.

The next experiments to consider are those with nitrate of soda alone (Series IV.). 1 N received, for nineteen years in succession, 275 lbs. nitrate of soda, containing nitrogen = 50 lbs. ammonia; and 2 N received, for the first five of the nineteen years, double the amount, or 550 lbs. = 100 lbs. ammonia, and afterwards, for fourteen years, only 275 lbs., as Plot 1 N. But as, in the first year of the twenty, both plots received superphosphate of lime and sulphate of potass in considerable amount, which doubtless increased the effects of the nitrogen subsequently supplied for many years, if not for the whole period, the results of 1 N are not strictly comparable with those of 1 A receiving annually the same amount of nitrogen as ammonia-salts, nor are those of 2 N comparable with those of 1 AA. As the figures stand, however, the average of twenty years with ammonia-salts, and of nineteen with nitrate of soda = 50 lbs. of ammonia, shows with the ammonia-salts 3.68 ammonia, and with the nitrate, nitrogen = only 2.74 lbs., required to yield 1 bushel increase of grain and its straw; and with the double amount during the first few years, the ammonia-salts show 3.53, and the nitrate only 2.81 lbs. required. It has already been explained (pp. 94-6) that enough phosphoric acid and potass were applied on the nitrate plots in the first year, to supply as much of these constituents as would be contained in the excess of produce by the nitrate over that by the ammonia-salts throughout the subsequent period; so that, obviously, only part of the better result of the nitrate can be supposed to be due to the condition of combination of its nitrogen.

The result is, at any rate, remarkable, that after mineral manures once applied, nitrate of soda alone should, for nineteen years in succession, yield a result in proportion to its nitrogen, comparatively so little inferior to ammonia-salts used every year in conjunction with superphosphate, or with superphosphate and salts of potass, soda and magnesia.

The next experiments are those of Series V., in which rape-cake was used without, and with mineral manures. During the first

6 years 2000 lbs., and during the last 14 years 1000 lbs. per acre per annum were applied. The rape-cake is calculated to contain 4.75 per cent. of nitrogen. This estimate is not founded on direct analysis of the lots actually employed, but is deduced from our own and published results on various samples in the market. Adopting it, the 2000 lbs. would contain 95 lbs. nitrogen = 115.4 lbs. ammonia, and the 1000 lbs., 47.5 lbs. nitrogen = 57.7 lbs. ammonia.

As the manure leaves a considerable residue for future crops, and would especially do so during the first 6 years, the calculation of the whole of the nitrogen supplied, against the increase obtained during that period, does not show the total or final effect of the nitrogen so supplied; whilst, during the succeeding 14 years, the figures will represent the result too favourably, in so far as a portion of the increase will doubtless be due to accumulation from the previous applications; and this would probably be more considerable, and more effective, than in the case of the double supply of ammonia-salts (Series II.). Accordingly, the figures show much more nitrogen applied for the production of a bushel of increase during the first 6, than during the last 14 years.

As already explained, the increase is, as in the experiments with ammonia-salts, calculated over the produce on the corresponding plots without nitrogenous manure. This plan is, upon the whole, less open to objection than taking the increase in each case over the unmanured produce; but a consideration of the results will show that it is by no means without objection.

The general result is, that the experiments with rape-cake show less difference and less beneficial effect due to the mineral manures also used, than those with ammonia-salts. Thus, comparing the results with rape-cake over the last 14, or the 20 years, with those of Series II., with ammonia-salts over the same periods (both manures being applied in double quantity during the first 6 years), considerably less nitrogen, reckoned as ammonia, is calculated to have been required to yield a given increase with ammonia-salts than with rape-cake when superphosphate was also used, but considerably less with rape-cake than with ammonia-salts, when each was used without superphosphate.

The fact is that rape-cake itself contains phosphates and other mineral constituents, which serve to render the nitrogen associated with them the more effective. It is obvious, therefore, that calculating the increase by the rape-cake alone over the produce without manure, and that by rape-cake and mineral manure over the produce by the corresponding mineral manure alone, gives a relatively too favourable result for the rape-cake where it is used alone, and too unfavourable where it is used with the mineral

manures. For, when used alone, the increase so reckoned as due to the nitrogen only, includes that due to the associated mineral constituents of the rape-cake; but when used with mineral manures, the increase due to the mineral constituents directly applied is deducted. On this point it may be mentioned that, if the increase were, in all four experiments with rape-cake, calculated over the unmanured produce, the result would appear, both actually and relatively, more favourable where mineral manures were also used, than the figures in the Table show.

The comparison between the ammonia-salts and the rape-cake is, of course, so far as the nitrogen is concerned, the fairest where the mineral conditions were the most equally favourable with both manures; that is where superphosphate was used. The less favourable result with the rape-cake under these conditions is, doubtless, due to its nitrogen becoming less rapidly available than that of the ammonia-salts. Still, upon the whole, it would appear that not very much more nitrogen is required in rape-cake than in ammonia-salts to yield a given amount of immediate increase; and an advantage of the rape-cake is, not only that it itself supplies mineral constituents, so that with it less superphosphate, if any, will be required, but that its nitrogen will probably be less liable to loss by drainage than that of ammonia-salts or nitrate of soda. On the other hand, a given amount of nitrogen costs more in rape-cake than in either sulphate of ammonia or nitrate of soda.

The last illustrations relate to the results obtained by farmyard manure. As in the case of the rape-cake, the quantity of nitrogen applied can only be approximately estimated. In the calculations it has been assumed that the dung contained 0.64 per cent. of nitrogen = 0.77 per cent. of ammonia. This result is arrived at by calculations founded on the average composition of the matters supposed to enter into the dung. It agrees almost precisely with determinations recently made in dung from the farmyard at Rothamsted; but it is rather less than has been found here in good box dung. It is almost exactly the mean of the results of Boussingault and Voelcker for fresh dung. But it is considerably higher than results recently published by Professor Anderson.

As has been stated, the produce on the farmyard-manure plot has increased considerably in recent years; and accordingly the Table shows much less nitrogen = ammonia required to yield a bushel of increase in the later than in the earlier years. There has indeed been a great accumulation, the effects of which have been only very gradually developed. Taking the average of the 20 years, however, it has required 8 lbs. of ammonia, or its equivalent of nitrogen, in dung, to yield one bushel increase of barley, and its straw; in other words, nearly four times as

much as when a mixture of ammonia-salts and superphosphate was employed. This is a striking illustration of the slowness of the return from nitrogen supplied in farmyard manure compared with that in ammonia-salts or nitrate of soda. It is obviously an important question whether less or more of the at first unrecovered amount is lost by drainage, or otherwise, in the one case than the other? or whether the residue from the one description of manure is more or less effective than that from the other? These points have already been referred to in some of their aspects, and will be further considered in the next Section (IV.); but data are still wanting for their full and satisfactory settlement.

From a review of the whole of the data brought forward relating to the point, the practical conclusion may be drawn, that when an increase of barley is obtained by means of artificial manures, such as sulphate of ammonia, or nitrate of soda, or Peruvian guano, an increase of 1 bushel of grain (52 lbs.), and its proportion of straw (say 63 lbs.), may, taking the average of seasons, be calculated upon for every 2 to $2\frac{1}{2}$ lbs. of ammonia, or its equivalent of nitrogen (1.65 to 1.86 lb.), supplied in the manure—provided the amount applied be not excessive, and provided there be no deficiency of mineral constituents within the soil.

These conditions will be fulfilled when barley, grown after dugged roots carted off, or after another corn crop, is manured by from $1\frac{1}{2}$ to 2 cwts. of sulphate of ammonia, or $1\frac{3}{4}$ to $2\frac{1}{4}$ cwts. of nitrate of soda, with 2 to 3 cwts. of superphosphate, per acre; or, from 3 to 4 cwts. of Peruvian guano, containing 12 per cent. of ammonia, without superphosphate.

When, however, rape-cake is used, rather more nitrogen in that form will be required to yield a given increase of the crop for which it is applied; but when the increase is obtained by sheep-folding, or farmyard manure, very much less will be obtained in the first crop, in proportion to the nitrogen contained in the manure.

In our Report on the growth of wheat for twenty years in succession on the same land, it was shown for that crop, as now it is for barley, that the quantity of increase obtained for a given amount of ammonia, or its equivalent of nitrogen, in manure, varied exceedingly according to the amount applied, to the provision of mineral constituents within the soil, and to the seasons. It was, however, stated, as a general practical conclusion, that, under the conditions the most comparable with those of ordinary practice, approximately 5 lbs. of ammonia, or its equivalent of nitrogen, were on the average required to yield 1 bushel increase of wheat, and its proportion of straw. Now,

1 bushel of wheat may be reckoned to weigh 61 lbs., and its average proportion of straw 105 lbs. Thus, whilst from 2 to $2\frac{1}{2}$ lbs. of ammonia in manure will yield 52 lbs. barley-grain, and 63 lbs. straw = 115 lbs. total produce, it required 5 lbs. to yield 61 lbs. of wheat-grain, and 105 lbs. straw = 166 lbs. total produce.

It is clear that it required much more nitrogen in manure to yield a given amount of increase of produce when applied in the autumn for wheat, than when in the spring for barley.

The questions remain—what proportion of the supplied nitrogen is recovered in the immediate increase of crop?—what becomes of the unrecovered amount, if any?—does it, wholly or in part, remain in the soil?—if so, what will be its effect on succeeding crops?—or, lastly, is there any material loss, by drainage, or otherwise? These points will next be considered.

SECTION IV.—ON THE EFFECTS OF THE UNEXHAUSTED RESIDUE FROM PREVIOUS MANURING UPON SUCCEEDING CROPS, LOSS OF CONSTITUENTS BY DRAINAGE, AND SOME ALLIED POINTS.

In the foregoing pages incidental reference has frequently been made to the effects of the residue from previous manuring upon succeeding crops; but the subject is, in various aspects, of such great importance, that it has been reserved for separate consideration in this place.

For example, it is of very great practical interest to have some exact data, showing—what proportion of the nitrogen, supplied in manure, will probably be recovered in the increase of the crop for which it is applied; whether, or in what degree, the at first unrecovered amount will, on the one hand be retained by the soil, or on the other, be drained away and lost? whether, if retained, it will remain, wholly, or in part, in such a state of combination, and distribution, within the soil, as to be available for succeeding crops? and so on.

Very similar questions obviously arise in regard to the mineral constituents of manures and crops; and so far at least as some of those constituents are concerned, it is very important to be able to refer to direct experimental evidence, bearing on the subject.

But, independently of facts and conclusions of great general interest and importance, when the same manure is applied, and the same crop grown, year after year on the same land, it is essential to a proper interpretation of the average results obtained over a series of years, not only to consider the characters of the seasons, but also whether any particular description of manure, so applied, induces exhaustion of certain constituents, resulting in

diminished, or accumulation tending to increased, productiveness from year to year.

In our Report on the growth of wheat for 20 years in succession on the same land, the question of the effects of the unexhausted residue from previous manuring upon succeeding crops, was considered so far as evidence was then at command, and it is proposed to give some further illustrations relating to that crop. The experiments on barley afford but few illustrations of the point; but it will be instructive to call attention to such as are available, to consider how far their indications agree with and how far they differ from, those relating to wheat, and to endeavour not only to explain the general facts observed, but to ascertain the reason of any differences of result with the two crops.

The effects of the unexhausted residue of nitrogen, supplied as ammonia-salts, or nitrate of soda, will first be considered.

Table XL. relates to experiments on barley with ammonia-

TABLE XL.—Effects of the Unexhausted Residue of Nitrogen applied to Barley with Ammonia-salts.

YEARS.	PRODUCE PER ACRE.							
	TOTAL CORN IN BUSHELS OF 52 lbs.			STRAW (and Chaff).			TOTAL PRODUCE (Corn & Straw)	
	Mixed Mineral Manure every Year, and—		4 AA over (or under —) 4 A.	Mixed Mineral Manure every Year, and—		4 AA over (or under —) 4 A.	Mixed Mineral Manure every Year, and—	
	Plot 4 A. 200 lbs. Ammonia-salts every Year.	Plot 4 AA. 400 lbs. Ammonia-salts, 6 Years, 1852-'57; 200 lbs., 10 Years, 1858-'67.		Plot 4 A. 200 lbs. Ammonia-salts every Year.	Plot 4 AA. 400 lbs. Ammonia-salts, 6 Years, 1852-'57; 200 lbs., 10 Years, 1858-'67.		Plot 4 A. 200 lbs. Ammonia-salts every Year.	Plot 4 AA. 400 lbs. Ammonia-salts, 6 Years, 1852-'57; 200 lbs., 10 Years, 1858-'67.
Average, 6 years, 1852-'57	Busbels. 49½	Busbels. 53½	Busbels. 4	Cwts. 29½	Cwts. 36½	Cwts. 7½	lbs. 5,863	lbs. 6,874
1858	55½	60½	5	29½	35½	6½	6,192	7,160
1859	38½	40½	1½	27½	30½	3½	5,067	5,517
1860	45½	48½	2½	26½	29	2½	5,355	5,746
1861	58½	60½	2½	30½	33½	3½	6,472	6,937
1862	52½	54½	1½	31½	33½	1½	6,273	6,529
1863	61½	65½	4½	32	34½	2½	6,791	7,323
1864	63½	63½	—0½	34½	37½	2½	7,225	7,469
1865	49	51½	2½	22½	24½	2½	5,075	5,469
1866	50½	56½	6½	27½	28½	0½	5,704	6,117
1867	47½	49½	2½	25½	28½	2½	5,304	5,733
Total ..	523½	551½	27½	287½	315½	28	59,458	64,020
Average	52½	55½	2½	28½	31½	2½	5,946	6,402

salts. The two Plots, 4 A and 4 AA, have received the same description and amount of mineral manure every year from the commencement. In addition, 4 A has received 200 lbs. of ammonia-salts per acre every year, but 4 AA 400 lbs., or double the amount the first 6 years, and only 200 lbs., or the same as 4 A, the next 10 years. Any increase, therefore, on Plot 4 AA over 4 A, during the 10 years in which they both received the same amount of ammonia-salts, may presumably be attributed to the extra amount applied to 4 AA during the first 6 years. For the sake of more exact comparison than the record of the actual quantities of dressed corn would afford, the total corn per acre has, in each case, been calculated into bushels of 52lbs.

It appears that, during the 10 years, there was an excess of produce on 4 AA compared with 4 A, due to the unexhausted residue from the previous nitrogenous manuring, of nearly 28 bushels of corn, and just 28 cwts. of straw; or an annual average of $2\frac{3}{4}$ bushels of corn, and $2\frac{3}{4}$ cwts. of straw. It is also to be observed that the excess in the tenth year was almost exactly the same as the average of the 10 years, showing that the residue was not even then exhausted. There was, then, in this case, a marked effect upon the succeeding barley crops, from the extra ammonia-salts applied in the first 6 years.

Table XLI. (page 128) shows, in like manner, the effects on succeeding barley-crops of a previous extra supply of nitrogen in the form of nitrate of soda. The two Plots, 1 N and 2 N, each received in the first year, 1852, $3\frac{1}{2}$ cwts. superphosphate of lime, and 300 lbs. sulphate of potass per acre. Each year since, 1 N has received 275 lbs. nitrate of soda, and 2 N 550 lbs. during the first 5 years, but subsequently only 275 lbs., or the same amount as 1 N.

The Table shows that, during the 14 years after the cessation of the extra application of nitrate on Plot 2 N, it continued to give more produce than 1 N, amounting in the 14 years to about $51\frac{1}{2}$ bushels of corn, and rather over 30 cwts. of straw, or to an average per acre per annum of $3\frac{2}{3}$ bushels of corn, and $2\frac{1}{3}$ cwts. of straw. Here, again, as in the experiments with the ammonia-salts, the increase in the last year of the series is almost precisely the same as the average increase over the whole period. The differences from year to year are obviously due to peculiarities of season. The result is clear, however, that with the nitrate, as with the ammonia-salts, there was a somewhat lasting effect from the extra amount applied during the earlier years.

It will be of much interest to compare the above results with barley, with those obtained with wheat; and it is especially desirable to adduce those which bear upon the point relating to

TABLE XLI.—Effects of the Unexhausted Residue of Nitrogen applied to Barley as Nitrate of Soda.

YEARS.	PRODUCE PER ACRE.								
	TOTAL CORN IN BUSHELS OF 52 lbs.			STRAW (and Chaff).			TOTAL PRODUCE (Corn and Straw)		
	Plot 1 N.	Plot 2 N.	2 N, over (or under —) 1 N.	Plot 1 N.	Plot 2 N.	2 N, over (or under —) 1 N.	Plot 1 N.	Plot 2 N.	2 N, over (or under —) 1 N.
	275 lbs. Nitrate Soda, 19 Years, 1853-'71.	550 lbs. Nitrate Soda, 5 Years, 1853-'57; 275 lbs., 14 Years, 1858-'71.		275 lbs. Nitrate Soda, 19 Years, 1853-'71.	550 lbs. Nitrate Soda, 5 Years, 1853-'57; 275 lbs., 14 Years, 1858-'71.		275 lbs. Nitrate Soda, 19 Years, 1853-'71.	550 lbs. Nitrate Soda, 5 Years, 1853-'57; 275 lbs., 14 Years, 1858-'71.	
Average, 5 years, 1853-'57	BusheLS. 45½	BusheLS. 51½	BusheLS. 5½	Cwts. 25½	Cwts. 31½	Cwts. 6	lbs. 5,226	lbs. 6,198	lbs. 972
1858	41½	47½	6½	20½	23½	3½	4,399	5,125	726
1859	26½	29½	2½	18½	21½	2½	3,500	3,905	405
1860	29½	32½	3½	16½	18½	1½	3,416	3,793	377
1861	42½	45½	2½	27½	29½	2½	5,260	5,665	405
1862	39½	42½	2½	24½	24½	—	4,793	4,959	166
1863	55½	58½	2½	30½	29½	—	6,265	6,366	101
1864	45½	52½	6½	24½	27½	3½	5,065	5,820	755
1865	40½	42½	2½	18½	21½	3	4,174	4,629	455
1866	36½	43½	6½	21½	23½	2½	4,275	4,941	666
1867	35½	38½	2½	21½	21½	—	4,234	4,438	204
1868	27½	27½	0½	18½	17½	—1½	3,530	3,366	—164
1869	39½	42½	3	24	27½	3½	4,759	5,313	554
1870	37½	43½	6	18½	19½	5½	3,456	4,413	957
1871	47½	50½	8½	29½	31½	2½	5,726	6,175	449
Total ..	545½	596½	51½	307½	338	30½	62,852	68,908	6,056
Average	39	42½	3½	22	24½	2½	4,489	4,922	433

the latter crop, since we are now enabled to give them for 8 years longer than at the time of the last Report.

Plots 5 and 16, referred to in Table XLII. (next page), were both variously manured during the first 8 years, 1844–1851. From 1852 to the present time, Plot 5 has every year received a mixed mineral manure containing superphosphate of lime, and sulphates of potash, soda, and magnesia; whilst Plot 16 received annually, for the first 13 years of the period, namely 1852–1864 inclusive, the same mixed mineral manure as Plot 5, but in addition the very excessive amount of 800 lbs. of ammonia-salts per acre per annum. For the crop of 1865, and since, however, Plot 16 has been left unmanured. The 800 lbs. of ammonia-salts would supply annually to the soil about 200 lbs. of ammonia = 164 lbs. of nitrogen; whilst, as will be seen further on, scarcely three-tenths as much was recovered in the average annual increase of wheat (corn and straw) during the 13 years of the application;

so that at the end of that period there remained seven-tenths, or more, of the large amount applied still to be accounted for.

TABLE XLII.—Effects of the Unexhausted Residue of Nitrogen applied to Wheat as Ammonia-salts.

YEARS.	PRODUCE PER ACRE.								
	TOTAL CORN IN BUSHELS OF 61 lbs.			STRAW (and Chaff).			TOTAL PRODUCE (Corn and Straw).		
	Plot 5.	Plot 16.	Plot 16, over (or under —) Plot 5.	Plot 5.	Plot 16.	Plot 16, over (or under —) Plot 5.	Plot 5.	Plot 16.	Plot 16, over (or under —) Plot 5.
	Mixed Mineral Manure alone, 20 Years, 1852-'71.	Mixed Mineral Manure, and 800 lbs. Ammonia- salts, 13 Years, 1852-'64; Unmanured since.		Mixed Mineral Manure alone, 20 Years, 1852-'71.	Mixed Mineral Manure, and 800 lbs. Ammonia- salts, 13 Years, 1852-'64; Unmanured since.		Mixed Mineral Manure alone, 20 Years, 1852-'71.	Mixed Mineral Manure, and 800 lbs. Ammonia- salts, 13 Years, 1852-'64; Unmanured since.	
Average, years, 52-'64	Bushels. 18½	Bushels. 40½	Bushels. 22	Cwts. 16½	Cwts. 46½	Cwts. 30½	lbs. 3,009	lbs. 7,713	lbs. 4,704
1865	15	34½	19½	10½	25½	15½	2,091	5,007	2,916
1866	13½	18½	4½	13½	17½	4½	2,303	3,081	778
1867	9½	14½	5½	9½	14½	5½	1,613	2,512	899
1868	18½	23½	5½	12	18½	6½	2,481	3,503	1,022
1869	15½	16½	1	14½	14½	0½	2,543	2,647	104
1870	19½	19½	0½	12½	12	-0½	2,564	2,557	-7
1871	12½	13½	1½	12½	13½	0½	2,207	2,380	173
total ..	104½	141½	37½	84½	116½	32½	15,802	21,687	5885
average	14½	20½	5½	12	16½	4½	2,257	3,098	841

Stated broadly and in round numbers, the result is as follows:—
By the actual utilization, or appropriation, of say three-tenths of the nitrogen annually supplied, there was obtained, over the 13 years of the application, an average produce of nearly 41 bushels of wheat grain, and more than 46½ cwts. of straw, or an average annual increase over the produce by the mixed mineral manure alone, during the same period, of 22 bushels of grain and 30 cwts. of straw. During the 7 succeeding years, the seven-tenths of the supplied nitrogen, which was not thus recovered in the increase of crop in the years of its application, yielded an average annual produce of only 20½ bushels of grain and 16½ cwts. of straw, or an average annual increase over the produce by the mineral manure alone (Plot 5) of only 5½ bushels of grain and 4½ cwts. of straw; whilst during the last 3 years there was scarcely any increase at all. In fact, of the 13 years application, and the 13 years unrecovered nitrogen, amounting to about seven-tenths of the whole supplied, less than the quantity left unrecovered in one year, was effective during the 7 succeeding

years; and, practically speaking, nearly the whole of the result was obtained during the first 4 years of the 7. It is true that the mixed mineral manure was not applied on Plot 16 as on Plot 5 during the last 7 years; but with the liberal application during the 13 years and previously, there could be no want of available mineral constituents within the soil; and even if the produce during the 7 years were compared with that without any manure, instead of with that with mineral manure, the annual increase from the residue would appear but little more, and the general result would remain substantially the same.

Again, Plots 5, and 17 and 18, particulars of which are given in Table XLIII. (next page), received during the first 8 years (1844-'51) various, but, upon the whole, very similar mixtures of mineral manures, ammonia-salts, and rape-cake; and, as the Table shows, they yielded very similar average annual amounts of produce during that period. In 1852, therefore, the plots were, practically, in very similar condition. For the produce of that year, and each year since, up to the present time, Plot 5 has received a mixture of superphosphate of lime, and sulphates of potass, soda, and magnesia. Over the same period, Plots 17 and 18 have received the same mineral manure, or ammonia-salts, alternately. For example, for the crop of 1852, Plot 17 received 400 lbs. ammonia-salts, and Plot 18 the mineral manure; for that of 1853, Plot 17 received the mineral manure, and Plot 18 the ammonia-salts; and so on, alternately, for the 20 years. Thus, in each year, the one or the other plot was manured with mineral manure, succeeding a dressing of ammonia-salts. These were conditions obviously very favourable for turning to account any residue of the nitrogenous manure of the previous year which might still remain in the soil in a state of combination, and distribution, such as to be available for the plant. The Table shows the produce obtained each year on Plot 5 by mineral manure year after year, and also that obtained each year by mineral manures after ammonia-salts, on Plot 17, or 18, as the case may be.

It is seen that the mineral manure on Plot 17, or 18, each year succeeding a liberal dressing of ammonia-salts for the crop of the previous year, gave, in 20 years, only $16\frac{3}{4}$ bushels of corn and $22\frac{1}{4}$ cwts. of straw, or annually only $\frac{3}{4}$ bushel of corn and $1\frac{1}{4}$ cwt. of straw, more than Plot 5, which received the same mineral manure every year without the interposition of any ammonia-salts.

The result is, then, that when 400 lbs. of ammonia-salts per acre were used for wheat, the unexhausted residue of nitrogen, if any, gave very little increase of produce in succeeding years;

TABLE XLIII.—Effects of the Unexhausted Residue of Nitrogen applied to Wheat as Ammonia-salts.

YEARS.	PRODUCE PER ACRE.								
	TOTAL CORN IN BUSHEL OF 61 lb.			STRAW (and Chaff).			TOTAL PRODUCE (Corn and Straw).		
	Plot 5. Mixed Mineral Manure alone, 20 Years, 1852-71.	Plots 17 or 18. Mixed Mineral Manure, every Year succeeding 400 lbs. Ammonia- salts; 20 Years, 1852-71.	Plots 17 or 18, over (or under -) Plot 5.	Plot 5. Mixed Mineral Manure alone, 20 Years, 1852-71.	Plots 17 or 18. Mixed Mineral Manure, every Year succeeding 400 lbs. Ammonia- salts; 20 Years, 1852-71.	Plots 17 or 18, over (or under -) Plot 5.	Plot 5. Mixed Mineral Manure alone, 20 Years, 1852-71.	Plots 17 or 18. Mixed Mineral Manure, every Year succeeding 400 lbs. Ammonia- salts; 20 Years, 1852-71.	Plots 17 or 18, over (or under -) Plot 5.
	Busbels.	Busbels.	Busbels.	Cwts.	Cwts.	Cwts.	lbs.	lbs.	lbs.
Average, 8 Years, 844-51	31½	32	0½	28½	29½	1	5,122	5,280	158
1852	17½	14½	-2½	17½	15½	-2½	3,019	2,621	-398
1853	9½	8½	-1½	18½	17½	-0½	2,640	2,534	-106
1854	25½	24½	-0½	22½	21½	-1	4,067	3,917	-150
1855	18½	19½	0½	16½	16½	0½	2,960	3,059	99
1856	19½	18½	-1½	18½	17½	-0½	3,274	3,111	-163
1857	23½	26½	2½	15	17½	2½	3,137	3,612	475
1858	19½	23	3½	14½	17½	3½	2,795	3,393	598
1859	20½	19½	-1½	21½	21½	0½	3,633	3,636	3
1860	15	15½	0½	14½	15½	1	2,539	2,678	139
1861	17½	19½	2½	13½	15½	1½	2,616	2,906	290
1862	18½	19½	1½	16½	18½	2	2,960	3,248	288
1863	21½	22½	1½	15½	17	1½	3,017	3,290	273
1864	17½	18½	0½	12½	13½	1½	2,462	2,654	192
1865	15	18	3	10½	13½	2½	2,091	2,568	477
1866	13½	13½	-0½	13½	13½	0½	2,303	2,328	25
1867	9½	10½	1½	9½	11	1½	1,613	1,893	280
1868	18½	19½	1½	12	14½	2½	2,481	2,807	326
1869	15½	16½	1½	14½	15½	0½	2,543	2,705	162
1870	19½	20½	0½	12½	12½	0½	2,564	2,628	64
1871	12½	16	-3½	12½	16½	3½	2,207	2,797	590
Total ..	349	365½	16½	299½	321½	22½	54,921	58,385	3464
Average	17½	18½	0½	15	16½	1½	2,746	2,919	173

whereas, when the same amount of ammonia-salts was used for 6 years in succession for barley, there was an excess of produce, doubtless due to the unexhausted residue of nitrogen, which averaged 2½ bushels of corn, and 2½ cwts. of straw, per acre per annum; for 10 years in succession, with evidence that the effect was not even then at an end.

Thus, it was shown in Sections II. and III. that a given amount of nitrogen in manure yielded more increase of barley than of wheat in the years of its application; and it is now seen that it also leaves a more effective residue when applied for barley than for wheat.

The questions arise—What proportion of the supplied nitrogen is, in either case, recovered in the increase of crop? What becomes of the unrecovered amount, if any? How is it that more increase is obtained, and that there is apparently less loss, in the case of the barley than of the wheat?

In our first paper in the 'Journal of the Royal Agricultural Society of England,' now more than twenty-five years ago, we pointed out that about 5 lbs. of ammonia in manure had been found necessary for the production of 1 bushel of increase of wheat and its straw. Frequently since, the question of the proportion of the nitrogen of manure recovered in the increase of produce obtained has been illustrated by results of the direct analysis of the produce. This was done, so far as barley is concerned, in the Report on the first 6 years of the experiments (Vol. xviii., 1858). In a paper "On the Annual Yield of Nitrogen per Acre in Different Crops," read at the meeting of the British Association for the Advancement of Science held at Leeds in 1858, it was concluded that, with wheat and barley indifferently, rather more than four-tenths of the supplied nitrogen was recovered in the increase. Again, in a paper "On the Sources of the Nitrogen of Vegetation, &c.,"* much the same estimate was arrived at for wheat, for barley, and for meadow-hay; and estimates were also made in regard to some other crops.

The subject is, however, one of such great importance, and the number of years over which the estimate can be made is now so much greater than formerly, that numerous new analyses have been made for the purposes of this paper. The nitrogen has thus been determined in the produce for 20 years (1852-1871), of six of the wheat, and five of the barley plots; also, but for 3 years only, in that of three of the experimental oat plots. For the oats the nitrogen has been determined in the grain and in the straw of each year separately; but, for the wheat, and for the barley, respectively, a mixture has been made of the produce (corn and the straw separately) of each plot, for the 20 years, the quantity taken being in exact proportion to the amount of produce per acre each year. The whole was then ground up together; so that the mixed samples respectively represent the produce of the grain and of the straw of each plot, for the 20 years.

Table XLIV. (p. 133) shows the amount of nitrogen recovered in the increase of produce (corn and straw), and the amount not recovered, for 100 supplied in manure.

For *wheat*, the plots selected are—that with 14 tons farmyard

* 'Philosophical Transactions,' Part II., 1861; also 'Jour. Chem. Soc.,' new series, vol. i., 1853.

TABLE XLIV.—Nitrogen Recovered, and not Recovered, in Increase of Produce, for 100 supplied in Manure.

Plots.	MANURES PER ACRE, PER ANNUM.	FOR 100 NITROGEN IN MANURE.	
		Recovered in Increase.	Not Recovered in Increase.
Wheat—20 Years, 1852–1871.			
6	Mixed Mineral Manure and 200 lbs. Ammonia-salts (= 41 lbs. Nitrogen)	82.4	67.6
7	Mixed Mineral Manure and 400 lbs. Ammonia-salts (= 82 lbs. Nitrogen)	82.9	67.1
8	Mixed Mineral Manure and 600 lbs. Ammonia-salts (= 123 lbs. Nitrogen)	81.5	68.5
16	Mixed Mineral Manure and 800 lbs. (1) Ammonia-salts (= 164 lbs. Nitrogen)	28.5	71.5
9 A	Mixed Mineral Manure and 550 lbs. (2) Nitrate Soda (= 82 lbs. Nitrogen)	45.3	54.7
2	14 tons Farmyard Manure every year.	14.6	85.4
Barley—20 Years, 1852–1871.			
4 A	Mixed Mineral Manure and 200 lbs. Ammonia-salts (= 41 lbs. Nitrogen)	48.1	51.9
4 A A	Mixed Mineral Manure and { 400 lbs. Ammonia-salts (= 82 lbs. Nitrogen) 6 years, 1852–57 .. } 200 lbs. Ammonia-salts (= 41 lbs. Nitrogen) 10 years, 1858–67 .. } 275 lbs. Nitrate Soda (= 41 lbs. Nitrogen) 4 years, 1868–71 .. }	49.8	50.2
4 C	Mixed Mineral Manure and { 2000 lbs. Rape-cake (= 95 lbs. Nitrogen) 6 years, 1852–57 .. } 1000 lbs. Rape-cake (= 47.5 lbs. Nitrogen) 14 years, 1858–71 .. }	86.3	63.7
7	14 tons Farmyard Manure every year.	10.7	89.3
Oats—3 Years, 1869–1871. *			
4	Mixed Mineral Manure and 400 lbs. Ammonia-salts (= 82 lbs. Nitrogen)	51.9	48.1
6	Mixed Mineral Manure and 550 lbs. Nitrate Soda (= 82 lbs. Nitrogen)	50.4	49.6

(1) 13 years only, 1852–1864.

(2) 475 lbs. Nitrate = 71 lbs. Nitrogen in 1852; 275 lbs. = 41 lbs. Nitrogen in 1853 and

(1) 13 years only, 1852-1864.

1854; 550 lbs. = 82 lbs. Nitrogen each year afterwards.

(2) 475 lbs. Nitrate = 71 lbs. Nitrogen in 1852; 275 lbs. = 41 lbs. Nitrogen in 1853 and

manure per acre per annum for 20 years; those with mixed mineral manure and 200 lbs., 400 lbs., 600 lbs., and 800 lbs., of ammonia-salts, per acre per annum; and that with the same mineral manure and 550 lbs. nitrate of soda per acre per annum.

For *barley*, the plots are—that with 14 tons farmyard manure per acre per annum for 20 years; that with the same mixed mineral manure as for the wheat, and 200 lbs. ammonia-salts per acre per annum for 20 years; that with the same mineral manure for 20 years, 400 lbs. ammonia-salts for the first 6 years, 200 lbs. for the next 10 years, and 275 lbs. nitrate of soda for the last 4 years of the 20; and that with the same mineral manure and 2000 lbs. rape-cake for the first 6 years, and 1000 lbs. for the next 14 years.

For *oats*—the plot with the same mixed mineral manure as for wheat and for barley, and 400 lbs. ammonia-salts; also that with the same mineral manure and 550 lbs. nitrate of soda per acre per annum, but for three years only.

The increase in the amount of nitrogen in the produce by the use of it in manure is, in the cases of the artificial mixtures of nitrogenous and mineral manure, calculated over the amount determined in the produce by the corresponding mineral manure without ammonia. The increase in the produce of nitrogen by farmyard manure is also calculated over that by the purely mineral manure.

According to the figures, there was, with the same mixed mineral manure and 200 lbs. of ammonia-salts per acre per annum for 20 years in succession, rather less than one-third of the supplied nitrogen recovered in the increase of the wheat, but nearly one-half in that of the barley.

With the same mineral manure, and 400 lbs. ammonia-salts applied for 20 years for wheat, and 400 lbs. for 6 years, 200 lbs. for 10 years, and 275 lbs. nitrate for 4 years—in all 20 years—for barley, there was recovered in the increase of the wheat, again scarcely one-third, but in that of the barley again nearly one-half. With the same mineral manure and 400 lbs. ammonia-salts applied to oats, but for 3 years only, there was even rather more than one-half of the supplied nitrogen reckoned to be recovered in the increase of crop.

When the more excessive amounts of ammonia-salts were applied for wheat, notably less than one-third of the supplied nitrogen was recovered, and the less the greater the excess.

On the other hand, when 550 lbs. of nitrate of soda (containing nitrogen = 400 lbs. ammonia-salts) were applied, there was, even with wheat, not much less than half, and with oats rather more than half of the nitrogen recovered in the increase of crop.

With rape-cake applied for barley, a considerably less proportion of the nitrogen was recovered than with ammonia-salts.

Lastly, with farmyard manure, whether applied to wheat or to barley, very much less of the supplied nitrogen was recovered than with any of the artificial manures. Indeed, assuming the dung to have provided about 200 lbs. of nitrogen per acre per annum, there was recovered in the increased produce of the wheat only about one-seventh, and in that of the barley scarcely one-ninth, of the nitrogen supplied by the manure.

The general result of this new and more extended inquiry is, then—that with neither crop is the whole of the supplied nitrogen recovered in the increase of produce obtained; that when a given amount of ammonia-salts was applied a much less proportion was recovered in wheat than in either barley or oats; but that, even with wheat, more was recovered when nitrate of soda was employed than when ammonia-salts were used.

How is the apparent loss to be explained? and how is it that a greater loss is observed with wheat than with either barley or oats?

In the paper in the 'Philosophical Transactions' (Part II. 1861),* already referred to, after showing the relation of the nitrogen in increase to that in manure in some particular cases, we submitted the following questions:—

"Is the unrecovered amount of supplied Nitrogen or at any rate a considerable proportion of it, drained away and lost?

"Are the nitrogenous compounds transformed within the soil, and their Nitrogen, in some form, evaporated?

"Does the missing amount for the most part remain in some fixed combination in the soil, only to be yielded up, if ever, in the course of a long series of years?

"Is ammonia itself, or Nitrogen in the free state, or in some other form of combination than ammonia, given off from the surface of the growing plant? Or, lastly,

"When Nitrogen is supplied within the soil for the increased growth of the Gramineous crop, is there simply an unfavourable distribution of it, considered in relation to the distribution of the underground feeders of the crop?—the Leguminous crop, which alternates with it, gathering from a more extended range of soil, and leaving a residue of assimilable Nitrogen within the range of collection of a next succeeding Cereal one?"

Briefly enumerated, the three main sources of loss of nitrogen here suggested are, then—*drainage; accumulation within the soil in a state of combination, or distribution, unfavourable for being taken up by the immediately succeeding crop; or evolution in some form from the surface of the growing plant.*

From some of the results reported in the same paper, and also

* "On the Sources of the Nitrogen of Vegetation; with special reference to the question whether plants assimilate free or uncombined Nitrogen." By Lawes, Gilbert, and Pugh.

from other considerations, we concluded, in opposition to the view we had previously been disposed to entertain, that the last-named of these, that is, *evolution from the plant*, did not take place.

With regard to *drainage*, the previous results of Professor Way,* and especially the subsequent ones of the experiments conducted at Rugby under our superintendence for the Royal Sewage Commission,† led us to attribute great importance to that part of the subject. In the course of that inquiry we arranged for the collection of sixty-two samples of drainage-water, the partial analysis of which was conducted by Professor Way; and, comparing the results with those on the corresponding samples of sewage, it was obvious that but a small proportion of the nitrogen of the sewage which was not obtained in the increase of produce was recovered in the drainage-water in the form of ammonia. We therefore arranged for the collection of some special samples for complete analysis, and especially for the determination of the nitric acid, if any, in both sewage and drainage-water. The results showed considerably more nitrogen in the drainage in the form of nitric acid than in that of ammonia. Indeed, it was obvious that a large proportion of that important manurial constituent of the sewage was drained away and lost. Satisfied for the time with this indication, it was not contemplated to follow up that part of our general inquiry until the question of the accumulation of nitrogen within the soil itself had first been investigated.

After the publication, in 1864, of the results of the growth of wheat for twenty years in succession on the same land, the subject of the composition of the crop, according to season and manure, was resumed; and it was determined to examine both the soils and the drainage-waters from the different plots, to see whether there was, on the one hand an accumulation of nitrogen in the soil, and on the other a loss by drainage. The nitrogen was determined in the first 9 inches, the second 9 inches, and the third 9 inches; or, in all, to a depth of 27 inches of soil. The results were given at the Meeting of the British Association for the advancement of Science at Nottingham, in 1866, and the following quotation from the abstract of that paper will indicate their general bearing:—

“The accumulation of nitrogen from the residue of manuring

* “On the Composition of the Waters of Land-Drainage and of Rain.” (*Journal of the Royal Agricultural Society of England*, vol. xvii. Part I.)

† “On the Sewage of Towns” (Third Report and Appendices 1, 2, and 3, of the Royal Commission, 1865). Also—“On the Composition, Value, and Utilisation of Town Sewage” (*Journal of the Chemical Society, New Series*, vol. iv.; entire series, vol. xix., 1866).

was found to be, in some cases, very considerable ; but even with equal amounts supplied, it varied, both in total amount and in distribution, according to circumstances, the depth to which the unused supply had penetrated being apparently influenced by the character and amount of the associated manurial constituents. The general result was, that, although a considerable amount of the nitrogen supplied in manure which had not been recovered as increase of crop was shown to remain in the soil, still a larger amount was as yet unaccounted for. Initiative results indicated that some existed as nitric acid in the soil, but it was believed that the amount so existing would prove to be but small. In fact, it was concluded that a considerably larger proportion would remain entirely unaccounted for within the soil to the depth under examination than was there traceable, and the probability was, that at any rate some of this had passed off into the drains, and some into the lower strata of the soil."

It was at the same time shown, by reference to field results, how very small was the increase of subsequent wheat crops due to the large residue of nitrogen accumulated in the soil, notwithstanding its amount was many times greater than that which would yield an increase of 20 bushels or more, if applied afresh to soil otherwise in the same condition.

Thus, then, it was established, that there was a considerable accumulation within the soil, of nitrogen supplied in manure and not recovered in the increase of the crop, but that there remained a considerable quantity not so accounted for ; and it was concluded that some of this had passed off into the drains, and some into the lower strata of the subsoil.

Being fully occupied at the time with other subjects, and finding that Dr. Voelcker was desirous to investigate the question of land drainage, we gladly provided him with samples of the drainage-water from the differently-manured plots in the experimental wheat-field, and also with full particulars of their history for the purposes of inquiry. In the 'Journal of the Chemical Society of London' (vol. ix. s.s. p. 291, 1871), Dr. Voelcker has published the results of the complete analysis of seventy samples of drainage-water of accurately known history so collected. Those results are a most valuable contribution to our knowledge of the subject, not only in its agricultural bearings, but also in relation to the question of the influence of the sources of potable and other waters upon their composition and quality. For the details we must refer the reader to Dr. Voelcker's own paper ; but the following table gives a summary of the results so far as they relate to the loss by drainage of the nitrogen supplied to the soil by manure.

TABLE XLV.—Composition of Drainage-water from Plots differently Manured; Broadbalk Field, Rothamsted; Wheat every Year, commencing 1844.

Nitrogen as Nitrates and Nitrites, per 100,000 parts of Water.
Dr. VOELCKER's Results.

DATES OF COLLECTION, &c.	MANURES PER ACRE, PER ANNUM.						
	14 Tons Farmyard Manure, every Year.	Without Manure, every Year.	Sulphate of Potass, Soda, and Magnesia and Superphosphate of Lime.				
			Without Nitrogen in Manure since 1851.	And 41 lbs. Nitrogen as Ammonia- salts.	And 82 lbs. Nitrogen as Ammonia- salts.	And 123 lbs. Nitrogen as Ammonia- salts.	And 82 lbs. Nitrogen as Nitrate Soda.
	Plot 2.	Plots 3-4.	Plot 5.	Plot 6.	Plot 7.	Plot 8.	Plot 9.
Dec. 6, 1866, full flow ..	1·956	0·648	0·878	1·330	2·170	2·567	0·707
May 21, 1867, full flow ..	..	0·052	0·059	0·089	0·078	0·274	0·785
Jan. 13, 1868, full flow ..	1·256	0·667	0·926	1·704	2·811	3·104	1·196
Apr. 21, 1868, full flow ..	..	0·085	0·137	0·189	0·448	0·578	5·830
Dec. 29, 1868, enormous flow	..	0·500	0·530	0·952	1·493	1·874	0·659
Means	1·606	0·390	0·506	0·853	1·400	1·679	1·835

The conditions under which the results given in the above (and the next) Table have been obtained, should be further described as follows:—With the exception of Plot 9, as explained below, each plot has been manured as stated in the Table every year, commencing 1852. Further, Plot 2 received 14 tons of farmyard manure every year, commencing 1843-4. The unmanured portion consists of two lands, Plots 3 and 4 respectively, the drain running under the furrow which separates them; Plot 3 has been unmanured since the commencement of the experiments in 1843-4, and for some years previously; whilst Plot 4 has only been unmanured since 1851; for which, and six preceding seasons, it received ammonia-salts and superphosphate of lime; the effects of the unexhausted residue from which are slightly apparent even up to the present time. Each of the other plots consists of two lands, the drain running under the separating furrow. For the crop of 1851, and several preceding seasons, Plot 5 received, besides mineral manure, ammonia-salts in rather heavy dressings, and also some rape-cake. The other plots also received various amounts of nitrogenous and mineral manure in 1851, and previously. Only one of the two lands comprising Plot 9 has received the mineral manure stated (commencing 1855); the other has had the nitrate alone: the quantity

of nitrate applied over the two lands was equal to only 71 lbs. nitrogen per acre in 1852, and to only 61 lbs. in 1853 and 1854, but to 82 lbs. in each year since.

In the first place it will be observed that, in three of the five occasions on which all the other drains ran freely, no result is given for the farmyard manure plot. The fact is that, whilst the pipe-drains from every one of the other plots in the experimental wheat-field run *freely*, perhaps four or five or more times annually, the drain from the dunged plot seldom runs at all more than once a year, and in some seasons not at all. We must refer to a former paper* for some further particulars relating to this very important result. Stated briefly, it was found that the dunged soil, when saturated, retained, within 12 inches from the surface, an excess of water which would be equivalent to about $1\frac{1}{2}$ inch of rain more than that held to the same depth on the unmanured and the artificially manured plots in the same field. The conclusion is obvious, that the dunged soil, with its vast accumulation of organic matter, and doubtless greater degree of disintegration, porosity, and power of absorption, especially near the surface, is enabled to retain much more water. Hence a much greater amount and continuity of rain is required to overcome its power of retention, and to reach the drains in its case. This result is one of very great interest and significance. Thus, whether the porosity of a clay soil be increased by the application of manure, by mechanical means, or by a combination of the two, its power to absorb and retain water, in an available and not injurious state, will be proportionately increased; and, not only will the growing crops be thereby rendered more independent of drought, but the necessity for artificial drainage will, at any rate in some soils, be greatly lessened.

Not only does the drain-pipe from the dunged plot seldom run, but it will be observed that the proportion of nitrogen in its drainage water is, in one of the cases given, less than where 82 lbs. of nitrogen were supplied as ammonia-salts, and in the other less than where 41 lbs. of nitrogen were so supplied. This is the case though the dung is estimated to supply to the soil nearly, if not quite, 200 lbs. of nitrogen per acre per annum. In connection with this point it may be stated that analysis of the soil of the dunged plot after 25 years of the application of the manure, showed that the top 9 inches contained nearly twice as high a percentage of nitrogen as the corresponding layer of any of the artificially manured plots. Yet, not once during the 29 years of the experiments has the farmyard-manured plot yielded as high a total produce (corn and straw together) as one or other of the plots manured with mixed mineral manure and ammonia salts or

* 'Journal of the Royal Agricultural Society of England,' vol. vii. s.s., Part I., p. 115.

nitrate of soda. It is obvious, that the nitrogen supplied by the dung is retained by the soil in a condition not only much less rapidly available to growing crops, but also much less liable to loss by drainage. Still, there is a large amount of the nitrogen supplied in the dung not yet satisfactorily accounted for.

The Table shows that at each period of collection there was less nitrogen in the drainage-water from the plot the whole of which has been unmanured since 1851, and part for a number of years previously, than from either of the plots artificially manured during the same period. There was, in every case, rather more from Plot 5, which received mineral manure alone in 1852, and each year since; but mineral manure in each, with ammonia-salts, or nitrogenous organic matter, or both, in 7 out of the 8 preceding years. There was, further, in each case, more nitrogen in the drainage-water when, to the mineral manure, ammonia-salts = 41 lbs. of nitrogen was added; with one slight exception again more when 82 lbs. were employed; and more still with 123 lbs. nitrogen supplied.

That is to say, with each increased supply of nitrogen by manure, as ammonia-salts, there was an increased loss of nitrogen as nitric acid in the drainage-water.

It must be borne in mind that, in the experiments on wheat here referred to, the ammonia-salts were always sown broadcast in the autumn, and ploughed or harrowed in before sowing the seed; and it is seen that the amount of nitrogen as nitric acid in the drainage-water is much greater on the three occasions of winter collection, that is, soon after the manures were sown, and when there was no growth, than on either of the two occasions of spring collection, that is, after the washing out by the winter rains, and when active growth had set in.

The nitrate of soda is, however, always sown as a top-dressing about the middle of March. Accordingly, there was, in each case of winter collection, much less nitrogen as nitric acid in the drainage from the nitrated plot (9), than in that from Plot 7, which received the same amount of nitrogen as ammonia-salts applied in the autumn. On the other hand, in both cases of spring collection—that is, after the sowing of the nitrate—the amount of nitrogen as nitric acid was much greater in the drainage from the nitrated plot, than in that from the plot which had received the same amount of nitrogen as ammonia-salts in the autumn. In one case, indeed, April 21, 1868, the nitrate having been applied on March 18, the quantity of nitrogen as nitric acid in the drainage from the nitrated plot amounted to 5.83 parts per 100,000 parts of water. Assuming (which, however, was probably not the case) that an inch of rain passed as drainage of that strength, this would represent a loss of about 13 lbs. of nitro-

gen per acre! On this point it may be stated that for every inch of rain carrying with it into the drains, or below the reach of the roots, 1 part of nitrogen per 100,000 parts of water, there will be a loss of $2\frac{1}{2}$ (2.26) lbs. of nitrogen of manure per acre. If this fact be clearly fixed upon the mind, its great practical importance cannot fail to be recognised.

Since this Section was in type, we have been favoured by Professor Frankland with numerous results of analysis of drainage-water from the differently manured plots in the experimental field at Rothamsted, samples of which had, at his request, been supplied to him for investigation. He has also been good enough to give us permission to publish some of the results obtained relating to the amount of nitrogen in the waters in the form of nitrates and nitrites. Accordingly, we have, with his approval, selected for illustration those relating to the same plots as in the case of Dr. Voelcker's analyses, and those relating to six different periods of collection are taken.

When considered in detail—with due regard to the supply of manure, to the previous rainfall, to the period of collection, to

TABLE XLVI.—Composition of Drainage-water from Plots differently Manured; Broadbalk Field, Rothamsted; Wheat every Year, commencing 1844.

Nitrogen as Nitrates and Nitrites, per 100,000 parts of Water.
Professor FRANKLAND's Results.

DATES OF COLLECTION, &c.	MANURES PER ACRE, PER ANNUM.						
	14 Tons Farmyard Manure, every Year.	Without Manure, every Year.	Sulphates of Potash, Soda, and Magnesia, and Superphosphate of Lime.				
			Without Nitrogen in Manure since 1851.	And 41 lbs. Nitrogen as Ammonia- salts	And 82 lbs. Nitrogen as Ammonia- salts.	And 123 lbs. Nitrogen as Ammonia- salts.	And 82 lbs. Nitrogen as Ni-rate Soda.
	Plot 2.	Plots 3, 4.	Plot 5.	Plot 6.	Plot 7.	Plot 8.	Plot 9.
Jan. 5, 1872, moderate flow	2.592	1.312	1.418	2.777	4.744	7.841	2.311
May 18, 1872, moderate flow	0.081	0.071	0.071	0.051	0.059	0.094	1.647
June 11, 1872, small flow	0	0	0	0	0	(¹)	(¹)
Oct. 26, 1872, moderate flow	0.932	0.366	0.360	1.354	2.303	1.808	0.975
Jan. 19, 1873, moderate flow	0.084	0.057	0.157	0.454	1.294	1.522	(²)
Feb. 26, 1873, small flow	0.082	0.131	0.088	0.122	0.461	0.441	0.264
Means	0.922	0.316	0.349	0.793	1.477	1.951	1.039

¹) In these cases the drains did not run; and as there was little or no loss of nitrogen from the water that did, it is assumed that there was little or none in these, and hence, for fair comparison, the means are—for Plots 3-4, 5, 6, 7, and 8, taken as for 6 experiments. For Plot 2, however, the means are only taken for 4, and for Plot 9 for 5, experiments.

²) On January 19, 1873, the drain from Plot 9 ran a little, but had ceased to do so when the samples were collected.

the growth of the crop, and to the rate of flow—these results of Dr. Frankland's not only strikingly confirm the conclusions drawn from those of Dr. Voelcker, but they afford additional points of interest. Thus, there is not only an obvious gradation in the amount of nitrogen, as nitrates and nitrites, comparing plot with plot, according to the amount of nitrogen supplied in the manure, but, dependent on the conditions above enumerated, there are both higher and lower amounts than in any of the cases investigated by Dr. Voelcker.

In the autumn of 1871 the farmyard-manure plot received its dressing on October 22nd, and the mineral manures and ammonia-salts were applied on October 18 and 22. During November, and the first half of December, there was much less than the usual amount of rain; about the 20th of December there was a fall of rather more than half an inch, and from that time to the end of the month there was more or less rain almost every day; giving, however, a total for the month of considerably less than the average. Still, the soil had gradually acquired a good deal of moisture; and, on December 30th, a few of the drains in the experimental wheat-field ran a little. There was a little rain registered on January 1, 2, and 3, 1872, more than one-quarter of an inch on January 4th, more than half an inch on January 5th, and again more than half an inch on January 6th. On January 4th a few of the drains ran, and on both the 5th and 6th the whole of them. The results given in the first line of the Table (XLVI,) relate to samples collected on January 5th, which was the first occasion on which all the drains ran since the application of the manures in October.

The drainage from the Plots 3–4, both of which have been entirely unmanured since 1851, and one for some years previously, shows the lowest proportion of nitrogen as nitrates; that from Plot 5, which had received mineral manure alone in 1852, and each year since, but mineral manure and ammonia-salts for several years previously, contained rather more; that from Plot 6, with ammonia-salts equal 41 lbs. nitrogen per acre per annum, much more; that from Plot 7, with ammonia-salts equal 82 lbs. nitrogen per acre per annum, again much more; and that from Plot 8, receiving 123 lbs. nitrogen per acre per annum, very much more still—in fact, more than in any other case examined by either Dr. Frankland or Dr. Voelcker, and an amount corresponding to a loss of $17\frac{1}{2}$ lbs. of nitrogen per acre, provided that an inch of rain passed away as drainage of that strength. The drainage from the nitrated plot, on the other hand, which had not received any nitrate since the previous spring, showed less loss of nitrogen than Plot 6, which

receives only half the quantity of nitrogen annually, but in the form of ammonia-salts, which had been applied in the autumn.

During the rest of January (1872) some of the drains ran very frequently, and nearly all of them more than once; in March, again, many of them ran twice, and on May 18th there was a discharge from all excepting that from the dunged plot. In fact, in January there was a great excess of rain; in February a fair amount; in March considerably more than the average; in April nearly the average; and in May a considerable excess. Up to the middle of May, therefore, the soil had been subjected to an unusual washing out; whilst growth would then have advanced considerably, and the roots would have established command over the soluble matters within the soil. The result is, that the amount of nitrogen in the drainage at that date was extremely small in all the cases of autumn manuring by ammonia-salts; but it was very much greater where the nitrate had been applied on March 7th. It is true that the actual amount of nitrogen as nitrates and nitrites in a given quantity of the drainage from the nitrated plot was less in May, after the sowing of the manure in March, than it was in January, when no nitrate had been sown, and a crop had been grown since the application of the manure in the previous March; but in May the quantity in the drainage from the nitrated plot was very many times greater than in that from either of the plots which had been manured with ammonia-salts, whilst in January it was less.

After the collection on May 18th, there was about one-third of an inch of rain before the end of the month, bringing up the total to notably more than the average. In June, again, there was an excess of rain, more especially during the first third of the month; on June 9th a few of the drains ran, and on June 11th most of them, though only slowly. Samples of the drainage from eight of the plots were sent to Dr. Frankland; and although in three of them a very small amount of nitrogen as nitrates and nitrites was found, the Table shows that there was none whatever in that from either of the plots to which the results there given refer. This is a very interesting fact; and it is doubtless accounted for, in part by the previous washing out of the soil, and in part by the extent to which the growing crop would, by the middle of June, have availed itself of assimilable nitrogen within the soil.

It only remains to add, in reference to the season thus far referred to, that, after such considerable loss by drainage during the winter, the crops in the experimental wheat-field which had been manured with mineral manure and ammonia-salts, applied in the autumn, were considerably below the average obtained under corresponding conditions in other years, whilst the produce

by mineral manure and nitrate of soda—the latter not applied until the spring—was considerably above the average.

From June 11th until October 25th none of the drains ran; but there was a flow from most of them on the 25th, 26th, and 27th of the latter month; and, as the Table shows, samples of the drainage of October 26th were collected and analysed. The dung had been put upon its plot on October 14th; the mineral manures and the ammonia-salts were sown on October 16th and 17th. There was more or less rain registered each day afterwards, until, on the 24th there was about one-third of an inch, on the 25th more than half an inch, and on the 26th nearly nine-tenths of an inch. These heavy rains had come on when the land was only partly ploughed, only one or two plots being finished, and some scarcely touched. At the time of the collection of the drainage, therefore (October 26th), scarcely two plots were in the same condition as to the working of the land, so that some irregularities in the relative composition of the waters would be expected. There was still, in the main, a gradation in the amount of nitrogen as nitrates in the drainage-water, according to the amount of ammonia-salts applied; but the quantities were, throughout, comparatively low for winter-drainage collected soon after the sowing of the manure. This was probably in part due to the soil not having been completely broken up, and the manures, therefore, not being thoroughly distributed, but partly also to washing out, or dilution, for many hours before the samples were collected.

Some of the drains ran, more or less, eight times during November, and most of them two or three times. In December, again, most ran six, and some seven times, completing a year of much more frequent running than any since the observation of them commenced in 1866.

On January 2, 4, and 5, 1873, the drains from all excepting the dunged plot, and on January 3rd, 10th, and 19th, from all, without exception, ran. On January 3rd there was a very full, but at each of the five other dates only a moderate, flow. On January 19th samples were collected from all the plots excepting No. 9, the flow from which had stopped when the collection was made. Since the collection on October 26, 1872, there had been about 5 inches more than the average fall of rain; some of the drains had run more than twenty, and most sixteen or seventeen, times; whilst, even since the beginning of the month, all but the dunged plot had previously run five times. Accordingly, after so much washing out of the soil, the amount of nitrogen as nitrates and nitrites was comparatively small for winter-drainage; but there was very obvious gradation in the amount according to the quantity of ammonia-salts which had been applied.

Between January 19th and February 26th there were frequent,

but not heavy rains (or snow-falls), but at the latter date about two-thirds of an inch of melted snow and rain were registered, all the drains ran, and samples were collected and sent to Dr. Frankland. After such an unusual washing out of the soil since the sowing of the manures in October, the drainage of February 26th is seen to contain, for that period of the year, a very small amount of nitrogen as nitrates and nitrites. There is still something like gradation according to the amount of nitrogen supplied in the manure; and, as would be expected, there is less in the drainage from the nitrated plot than in that from Plot 7, which receives the same amount of nitrogen annually, but applied as ammonia-salts in the autumn.

In connection with the very unusually large amount of water passing from the land by drainage during the past winter, 1872-73, it is of much interest to remark that, whilst at the present time (June 1873) the plots in the experimental wheat-field which received their dressing of ammonia-salts in October, are looking very much worse than usual, in fact, extremely unpromising, others, which were top-dressed with ammonia-salts or nitrate of soda in March, show much greater luxuriance.

With regard to the dunged plot (2), it has been explained (p. 139), that, owing to the greatly increased porosity of the soil by the application of farmyard manure so many years in succession, the drains from it very seldom run. It happens, therefore, that they do so only when there is a very great excess of rain; and, when there is such excess, a surface-drain, which first crosses the furrows of all the other plots, then crossed that of the dung, and passed not many yards from the outfall of that plot, has generally been running, so that there has sometimes been doubt whether the drainage from the dunged plot were not more or less affected by the percolation of this surface-water. Other cross-surface drains have, however, from time to time, been cut, to obviate this as far as possible; and it is believed that, at any rate during the past winter, there has been no danger of such percolation. Moreover, the results relating to Plot 2, recorded in the Table, though so different at the four periods of collection, are so far consistent with each other that, in each case, the drainage-water contains somewhat less nitrogen as nitrates and nitrites than that collected at the corresponding date from Plot 6, which received only 41 lbs. of nitrogen per acre per annum, but in the form of ammonia-salts; whilst, as already stated (p. 139), the dung is estimated to supply nearly, if not quite, 200 lbs. of nitrogen per acre per annum. But there has been a great accumulation of the nitrogen supplied by manure in the soil of the dunged plot, especially near the surface, and very much more than in that of the plots manured with ammonia-salts or

nitrate of soda. It is further worthy of remark, that there is a general consistency between these results relating to the drainage from the dunged plot, and those obtained by Dr. Voelcker; for, in one case examined by him, the amount of nitrogen as nitrates, &c., also ranged somewhat below that in the drainage from Plot 6, and in the other not much above it.

In regard to wheat, therefore, it has been experimentally established, that, even when a comparatively moderate amount of ammonia-salts was applied as manure, only about one-third of the nitrogen so supplied was recovered in the increase of the crop; that the unexhausted residue, if any, was but very slowly, and very partially recovered as increased yield in succeeding years; that, nevertheless, there was an accumulation within the soil itself, of some of the nitrogen not at first recovered in increase; but that there was a loss by drainage which increased almost in proportion to the amount of nitrogen supplied in the manure.

The question arises—whether the whole of the supplied nitrogen which is not recovered in the crop either remains in the soil, or is lost by drainage?

Owing to the difficulty of determining with certainty, either the total amount of nitrogen retained by the soil within the reach of the roots, the proportion of the total rain passing beyond their reach, or the average composition of the drainage, absolute proof on this point is not at command. The following illustration will nevertheless be useful.

Of the total nitrogen supplied to the wheat plot No. '7, during the 20 years, 1852–1871, it may be assumed that about 33 per cent. was recovered in the increase of crop, leaving 67 per cent. to be otherwise accounted for. The determinations of nitrogen made in the samples of soil collected in 1865 are obviously not strictly applicable to the present calculation; but from them it may perhaps be concluded that approximately one-third, or possibly more, of the nitrogen not recovered in the increase of crop, remains accumulated within the soil to the depth of the 27 inches examined. This would leave say 44 per cent. of the 82 lbs. of nitrogen annually applied as manure, or, in other words, an average of 36 lbs. of nitrogen, to be annually accounted for by drainage or otherwise. Now, there can be no doubt that by far the larger proportion, though not the whole, of the drainage takes place during the autumn and winter months; and taking the mean of Dr. Voelcker's three determinations of nitric-acid in the winter drainage from this plot, the amount of nitrogen so found in it is 2.16 parts for 100,000 of water. As 1 inch of rain is equal to a fall of 226,263 lbs. (about 101 tons) of water per acre, every inch passing as drainage beyond the reach of the roots, and containing 1 part of nitrogen per 100,000, would carry with it 24

(2.26) lbs. of nitrogen per acre; and 2.16 parts per 100,000 would represent a loss of nearly 5 (4.88) lbs. per acre for each inch of rain so passing. At this rate it would require little more than 7 (7.38) inches of rain to pass beyond the reach of the roots to account for the whole loss of nitrogen observed in the case of the wheat plot No. 7.

We have said that the actual amount of drainage is unknown; and since, in the case of the land in question, the subsoil of clay rests upon chalk at from 6 to 10 feet from the surface, and there is, therefore, natural drainage constantly going on, no gauging of the flow of the pipes, however exact, would indicate the total amount of water passing. Other experiments at Rothamsted have, however, proved, that from one-third to one-half of the annual rain may pass below 40 inches. Supposing only one-third of the total fall so to pass, an average of from 8 to 9 inches of rain would annually drain away, by far the greater proportion of which would go off during the autumn and winter months.

The quantity and composition of the drainage-water here supposed would obviously be sufficient to account for more than the whole of the loss of nitrogen from Plot 7 as above indicated. On the one hand, however, some allowance in the way of deduction must be made for the amount of nitrogen as nitrates and nitrites in the drainage, due to accumulations within the soil prior to the period included within the estimate, or to other normal annual sources; but whether, with the large annual supply of nitrogen by manure, and the much more active root development, in the case of Plot 7, the amount of nitrogen in the drainage-water from that plot, due to sources other than the annual direct supply of nitrogenous manure, would be as much as that indicated in the drainage from either plots 3, 4, or 5, may be a question. On the other hand, the proportion of the drainage to the rain-fall, in the case of the soil in question, would probably average more than one-third, which amount only is assumed in the above estimate.

Although the selection of samples sent to Dr. Frankland was very fortunate, so far as the illustration of the wide difference in the composition of the drainage from the same plot at different times is concerned, his results are, on that account, the less directly available as a means of forming a judgment of the probable *average* composition of the drainage throughout any particular season of the year. To this end it would be desirable to have had results relating to the period between January 5 and May 18, 1872; and again to that between October 26, 1872, and January 19, 1873. Still, taking Dr. Frankland's results as they stand, the mean proportion of nitrogen as nitrates and nitrites in the samples of drainage from Plot 7, collected on

January 5 and October 26, 1872, and on January 19 and February 26, 1873, is higher than that in the winter drainage from the same plot examined by Dr. Voelcker, and adopted in the illustrations above given.

It should be added that, even the drainage from the plots manured exclusively with mineral manure and ammonia-salts or nitrate of soda would appear, according to Dr. Frankland's analyses, to contain nitrogen as ammonia and organic nitrogen, in amount averaging about 4 or 5 per cent. as much as that found as nitrates and nitrites, and by so much, therefore, increasing the loss of combined nitrogen by drainage, beyond that indicated by the quantity of nitrates and nitrites alone. In the drainage from the dunged plot, however, the amount of ammonia and organic nitrogen is, both actually, and relatively to the quantity as nitrates and nitrites, much more than in that from the artificially manured plots.

From the foregoing considerations it seems extremely probable that the whole of the nitrogen applied to the wheat as ammonia-salts or nitrate of soda, was either recovered in the increase of the crop, accumulated within the soil, or lost by drainage.

As the experimental barley-field is not artificially drained, we are unable to illustrate the point in the same manner in regard to the barley as to the wheat crop. It has, however, been conclusively shown that, in the case of the barley, a greater amount of increase is obtained for a given quantity of nitrogen in manure than in that of the wheat; and that a larger proportion of the nitrogen supplied is recovered in the increase of produce within a given time. How are these facts to be explained?

From the facts adduced, it is clear that a material loss of nitrogen takes place by drainage in the winter, when ammonia-salts are applied in the autumn for the wheat crop; and since the manures for the barley are not sown until the spring, all loss of the freshly-supplied nitrogen by winter rains is avoided. Further, not only would there be comparatively little drainage after the spring sowing, but growth being at once established, the nitrogen, whether applied in the form of ammonia or of nitrate, would be rapidly taken up. The analyses of the drainage from the wheat-field show that the water collected during the spring contained, compared with that of the winter, very little nitrogen. This is probably partly accounted for by the previous washing out of the soil in the winter, but it is doubtless also in a great measure due to the action of the growing crop. It is only what would be expected, therefore, that a given quantity of ammonia-salts applied for barley in the spring, should yield a much better result than an equal amount applied for wheat in the autumn.

Even in the wheat experiments, nitrate of soda has always

been applied in the spring ; but as, unfortunately, the same quantities have not been applied for the two crops, no exact comparison can be drawn between the results they respectively yield. Still, the evidence undoubtedly indicates that more increase has been obtained for a given amount of nitrate when applied to barley than to wheat. In this case, therefore, loss by winter drainage cannot account for the comparatively defective result with the latter crop. Part of it is probably due to the fact that the quantity which has been applied for wheat (550 lbs. per acre) is a heavy spring dressing ; and, owing to the great solubility of the nitrate, and the little power of retaining it which the soil possesses, there would be a greater loss by spring and summer drainage the greater the quantity applied. In confirmation of this view, Dr. Voelcker's analysis of the drainage from the nitrated plot after the manure had recently been sown, showed twice as much nitrogen as he found in any case of winter drainage from plots receiving the same amount of nitrogen as ammonia-salts. In many seasons too, the crop is too heavy and laid. For barley, on the other hand, only half the amount of nitrate is used ; and, consequently, there will probably be not only less loss of manure by drainage, but less loss of crop by laying.

With regard to the supposition that there was probably a less proportional loss of nitrogen by drainage from the nitrate when applied for the barley than for the wheat, it should further be borne in mind, that although the manure is for both crops sown in the spring, yet it is in the one case on land in a close and consolidated condition, and in the other on soil rendered as light and open as possible by recent working, and hence offering a greater surface for absorption and retention of the manure. There is probably also a more active root-development in the upper layers of the soil in case of the barley than in that of the wheat.

Whether or not the above suppositions afford an adequate explanation of the difference of result with the nitrate when applied to both crops in the spring, the difference in the case of the ammonia-salts applied for the wheat in the autumn, and for the barley in the spring, is at any rate much more conclusively accounted for. But there is another circumstance in connection with the point that should not be overlooked.

The proportion of the nitrogen of the ammonia-salts which is recovered in the increase of produce being much greater in the case of the barley experiments than in those with wheat, there remains, of course, much less to be accounted for by accumulation in the soil, and by drainage. There is pretty certainly much less loss by drainage. And, so far as the few determinations of nitrogen that have yet been made in the soils of the barley plots enable us to judge, it would seem probable that there is less accumulation in the soil also, especially in the lower layers. If

this be really so, the explanation is that, as the application of the ammonia-salts for the barley is made with the soil in a more porous condition, when there is less risk of saturation by water, therefore less risk of washing out, and when growth almost immediately succeeds, the wide distribution of the ammonia (or of the nitrate resulting from its oxidation) is materially checked; whilst the residue thus remaining near the surface will be the more easily available to the abundant surface rootlets of succeeding barley crops. In this there would obviously be an element in the explanation of the greater effect upon succeeding crops, of the nitrogen of manure not recovered in the immediate increase, when it was applied in the spring for barley than when in the autumn for wheat.

The long continued effect from previous applications of nitrate of soda must obviously be explained in a very different way. As already referred to, a given surface of soil has much less power to retain either nitrate of soda, or other nitrates, than ammonia. Consequently, the nitrogen of the nitrate distributes much more rapidly, and widely, through the soil and subsoil, and, so far, is more liable to loss by drainage. On the other hand it has been explained (p. 56) that the effect of the nitrate, or its products of decomposition, is to cause the disintegration of the clay subsoil, and so to increase its porosity, and, therefore, its surface for the absorption and retention both of moisture and of manurial matters, and also its permeability to the roots. Hence, although a given surface of the clay subsoil will retain much less nitrogen as nitric acid than as ammonia, the surface itself being much increased, the defective power of retention of a given surface will, in so far, be compensated. Accordingly, it has been seen that the barley crop was much more independent of drought on the nitrated plots than on those manured with a corresponding quantity of nitrogen as ammonia-salts; and not only so, for there would appear to be a retention of nitrates by the subsoil, beyond that which would be anticipated considering their solubility; a result which is most probably due to the same increase of disintegration, porosity, and surface, as is assumed to account for the increased retention of moisture in the first instance, and subsequent extended development of root, and yielding up of water to the plant.

At any rate, whatever may be the exact explanation in either case, the facts are undoubted—that there was a considerable effect on succeeding barley crops from previous applications of nitrogen, both as ammonia-salts and as nitrate of soda; and that much greater effects, due to the residue of the supplied nitrogen, were observed when ammonia-salts were applied for barley in the spring, than when for wheat in the autumn.

To the foregoing illustrations of the effects of the unexhausted residue from previously supplied nitrogen, must be added some evidence as to the effects on succeeding crops of previously supplied mineral manures, or ash-constituents. The experiments on barley do not furnish absolutely unexceptionable comparative evidence on the point; though there can be little doubt that the superphosphate and sulphate of potass applied in the first year, 1852, on Plots 1 N and 2 N, have materially increased the effects of the nitrate of soda afterwards annually applied up to the present time. The experiments on wheat do, however, afford very conclusive evidence on the subject, and as we are now able to give the results of eight more seasons than when writing on the question in 1864, we append the following Table (pp. 152-3) relating to that crop.

For the crop of 1844, both plots, 10*a* and 10*b*, received a mineral manure, consisting of silicate of potass and superphosphate of lime. Every year since, 10*a* has been manured with ammonia-salts alone. 10*b* has been manured exactly similarly in every year excepting the third, fifth, and seventh (1846, 1848, and 1850); in 1846 it was left unmanured; in 1848 it received, in addition to the ammonia-salts, a mineral manure containing salts of potass, soda, and magnesia, and superphosphate of lime; and in 1850 the same mineral manure without the ammonia-salts. That is to say, during the first six years of the twenty-seven, the application of ammonia-salts was twice omitted on 10*b*, but it twice received mineral manure when 10*a* did not.

The Table shows that during the 6 years, 1845-50, 10*b*, with less ammonia-salts, but more mineral manure, yielded, in the aggregate, $14\frac{2}{3}$ bushels less corn, and $11\frac{1}{2}$ cwts. less straw, or $2\frac{1}{2}$ bushels corn, and $1\frac{7}{8}$ cwt. straw, less per acre per annum than 10*a*. On the other hand, in almost every year since up to the present time, a period of 21 years since the last application of mineral manure, 10*b* has yielded more of both corn and straw than 10*a*; in all $69\frac{2}{3}$ bushels more corn, and $61\frac{1}{8}$ cwts. more straw, or an average annual excess of $3\frac{2}{3}$ bushels of corn, and $2\frac{7}{8}$ cwts. of straw.

It is obvious that the excess of produce on 10*b*, over that on 10*a*, during the last 21 years, may be partly due to the less exhaustion of the mineral constituents of the soil on 10*b* during the first 6 of the 27 years, owing to the less supply of ammonia-salts to it during that period. But, if we deduct the difference between the produce on the two plots during these 6 years, from the excess of produce on 10*b* during the last 21 years, we still have, during the latter period, an aggregate excess of $54\frac{2}{3}$ bushels of corn, and $50\frac{2}{3}$ cwts. of straw, or an average annual excess of $2\frac{2}{3}$ bushels of corn, and $2\frac{1}{8}$ cwts. of straw, on 10*b*,

TABLE XLVII.—EXPERIMENTS ON WHEAT.

Effects on succeeding Crops, of the Unexhausted Residue from previous Applications of Mineral, or Ash-constituents.

YEARS.	PRODUCE PER ACRE.									
	TOTAL CORN IN BUSHELS OF 61 lbs.			STRAW (and Chaff).			TOTAL PRODUCE (Corn and Straw).			
	MINERAL MANURE, 1844.			MINERAL MANURE, 1844.			MINERAL MANURE, 1844.			
	Plot 10a. Ammonia- salts, 1845 and each year since. 27 years, 1845-71.	Plot 10b. Ammonia-salts, 1845 and each year since, excepting 1846 and '50; Unmanured 1846; Mineral Manure, 1843 and '50.	10b over (or under -) 10a.	Plot 10a. Ammonia- salts, 1845 and each year since, 27 years, 1845-71.	Plot 10b. Ammonia-salts, 1845 and each year since, excepting 1846 and '50; Unmanured 1846; Mineral Manure, 1843 and '50.	10b over (or under -) 10a.	Plot 10a. Ammonia- salts, 1845 and each year since, 27 years, 1845-71.	Plot 10b. Ammonia-salts, 1845 and each year since, excepting 1846 and '50; Unmanured 1846; Mineral Manure, 1843 and '50.	10b over (or under -) 10a.	
1844	BusheLS. 16½	BusheLS. 16½	BusheLS. ..	Cwts. 9½	Cwts. 9½	Cwts. ..	lbs. 2,120	lbs. 2,120	lbs. ..	
6 years, { 1845-'50 {	175½	161½	-14½	158½	146½	-11½	28,436	26,263	-2,173	
	29½	26½	-2½	26½	24½	-1½	4,739	4,977	-362	
1851	32½	31½	-.0½	27½	27½	-0½	5,036	4,985	-51	
1852	21½	22	0½	24½	25½	0½	4,107	4,162	55	
1853	10½	14½	4½	18½	24	5½	2,691	8,578	887	
1854	36½	41½	5½	32½	39½	7½	5,808	7,003	1,195	
1855	21	29½	8½	22½	29½	6½	3,797	5,073	1,270	

1856	24½	28½	8½	25½	28½	3½	4,823	4,895	572
1857	29½	35½	6	21½	25½	4½	4,208	5,060	852
1858	23½	29	5½	19	23½	4½	8,569	4,890	821
1859	19½	24½	4½	24½	30½	6½	8,937	4,920	983
1860	14½	17½	2½	19½	21½	1½	8,118	3,420	802
1861	14	16½	2½	17½	19½	2½	2,784	3,196	412
1862	23½	26½	2½	23½	25½	2½	4,050	4,443	893
1863	42½	46½	4½	31½	86½	5½	6,068	6,914	846
1864	34½	39½	5	25½	29	3½	4,925	5,642	717
1865	27	31½	4½	21½	25½	2½	4,034	4,615	581
1866	27½	30½	2½	24½	27½	2½	4,485	4,895	410
1867	18½	20½	1½	18½	19½	1	3,146	3,375	229
1868	26½	30½	3½	19½	21½	1½	3,790	4,210	420
1869	19½	19½	— 0½	20½	19½	— 0½	3,475	3,374	— 101
1870	23½	24½	1½	14½	15½	1½	3,047	3,244	197
1871	11	10½	— 0½	11½	12	0½	1,927	2,002	75
21 years, { Total ..	502½	570½	63½	460½	522½	61½	82,325	98,396	11,071
1851-71 { Average	23½	27½	3½	22	24½	2½	3,920	4,447	527

which amounts at least must be attributed to the residue of the mineral manures supplied now more than 20 years ago.

The wheat experiments afford other illustrations of the lasting effects of certain mineral substances applied as manures; but owing to the very unusual exhaustion of the mineral constituents of the soil by the application of ammonia-salts alone so many years in succession in the cases above cited, the point is sufficiently forcibly brought out to render it unnecessary to adduce further evidence of the same kind on the subject.

The evidence afforded by the analysis of the produce, of the soils, and of the drainage waters, is, however, perfectly consistent with that of the field results.

Thus, numerous analyses of the ash of the grain and the straw of the produce of the experimental wheat plots show that of Plot 10a to have become relatively deficient, more particularly in phosphoric acid, but to some extent in potass also, during the later years.

Again, Baron Liebig's son, Hermann von Liebig, who had asked to be provided with samples for investigation, has partially analysed the soils from some of the Rothamsted experimental wheat plots; and, so far as the important constituents potass and phosphoric acid are concerned, he finds the amount of these much greater, especially in the upper layers of the soil, the greater the supplies by manure.

Lastly, on this point, Dr. Voelcker's analyses of the drainage waters show, that very much less of potass passed off in that way than of either soda, lime, or magnesia; and also very much less of phosphoric acid than of sulphuric acid or of chlorine; in fact, there is comparatively little loss by drainage of either.

The facts brought out in this Section may be briefly summarised as follows:—

1. When either ammonia-salts, or nitrate of soda, or nitrogenous organic matter in the form of rape-cake, or farmyard manure, was applied for either wheat or barley, a considerable proportion of the nitrogen so supplied remained unrecovered in the increase of the crop for which the manure was employed; nor was the whole recovered in many succeeding crops.

2. When ammonia-salts were applied in the autumn for wheat, a much less proportion of their nitrogen was recovered in the increase of crop, than when they were applied in the spring for barley or for oats.

3. Analysis of the soils to the depth of 27 inches, showed that there was a considerable accumulation within that depth, of the nitrogen of manure which had not been recovered in the increase of the crop; but that a still larger amount remained to be otherwise accounted for.

4. Analysis of the drainage waters from the experimental wheat plots showed that they contained a large amount of nitrogen in the form of nitrates; that the quantity of nitrates in the drainage was the greater the greater the amount of ammonia-salts applied as manure; and that (after autumn sowing), the quantity was very much greater in the winter, than subsequently in the spring and summer.

5. The analysis of the drainage waters further showed—that the winter drainage, after sowing ammonia-salts in the autumn, may often contain from two to three parts (and sometimes much more) of nitrogen (as nitrates and nitrites) per 100,000 parts of water. Calculation showed that, for every one part of nitrogen per 100,000 parts of drainage, there will be a loss of $2\frac{1}{2}$ lbs. of nitrogen per acre for every inch of rain passing beyond the reach of the roots. In one case Dr. Frankland's analysis showed 7·841 parts of nitrogen per 100,000 parts of drainage, corresponding to a loss of $17\frac{1}{2}$ lbs. of nitrogen per acre, provided an inch of rain passed as drainage of that strength.

6. A given surface of soil possesses much less capacity of absorption for nitrate of soda, or its products of decomposition, than for the ammonia of ammonia-salts. Consequently, heavy rains soon after sowing would carry off in the drainage water more nitrogen from a dressing of nitrate of soda, than from a corresponding dressing of ammonia-salts. In one case, after a heavy dressing of nitrate of soda in the spring, Dr. Voelcker found the drainage-water to contain 5·83 parts of nitrogen per 100,000 of water, corresponding to a loss of 13 lbs. of nitrogen per acre, per inch of rain so passing.

7. Owing to the much less loss by drainage in the case of spring than of winter sowing, there was not only more increase in the immediate crop from a given amount of nitrogen applied in the spring for barley (or oats) than in the autumn for wheat, but there was also much more effect upon succeeding crops, from the at first unrecovered amount, in the case of the barley than in that of the wheat.

8. It is probable that the whole of the nitrogen supplied as manure in ammonia-salts, or nitrate of soda, is either recovered in the immediate increase of crop, retained in the soil in a very slowly available condition, or drained away and lost.

9. Owing to the slow decomposition of the nitrogenous organic matter of rape-cake and farmyard manure, their nitrogen is less rapidly available than that of ammonia-salts or nitrate of soda; but, so far as can be judged from the direct experiments on the point, it would appear to be, at the same time, less subject to loss by drainage.

10. Certain important mineral or ash-constituents of manures

—potass, and phosphoric acid, for example—are, at any rate in the case of the heavier soils, almost wholly retained by them within the range of the roots; and they are found to be very lasting in their effects upon succeeding crops, provided there be a sufficient available supply of nitrogen within the soil.

SECTION V.—RESULTS OBTAINED IN OTHER FIELDS, AND UNDER OTHER CONDITIONS AS TO CROPPING, MANURING, &c.

Before attempting to give a general summary of the results of the experiments on the growth of barley for 20 years in succession on the same land, or to draw any general or practical conclusions from them, it will be well to call attention to some results obtained in other fields, and under different, and in some cases less artificial, conditions as to cropping, manuring, &c. By the aid of the comparisons thus afforded, some judgment may be formed as to whether any conclusions drawn from the results obtained under the unusual conditions of the experiments which have been detailed, may be trusted as a guide to the requirements of the crop when grown on other land, or in the ordinary course of farming.

Two sets of experiments will be noticed. In the first of these, barley was grown for 3 years in succession on a series of plots which had previously been differently manured, and grown 10 crops of turnips in succession. In the other case, barley has been grown in four-course rotation, without manure, and with different descriptions of manure.

1. *Three Years of Barley after Ten Years of Turnips— Barn Field.*

The results of these experiments were considered in some detail in our former paper on the Growth of Barley ('Journal of the Royal Agricultural Society of England,' vol. xviii., Part II., 1858), and they will therefore be referred to less fully in this place.

For the turnips, the area of from 7 to 8 acres was divided into numerous plots, differently manured; and the object in view in afterwards taking 3 unmanured barley-crops from the land was to test the actual and comparative condition for corn-growing, in which the different plots had been left, and, as far as possible, to equalize their condition (especially so far as the nitrogen which had been supplied was concerned), before commencing a new series of turnip experiments.

The turnips were grown in the 10 years 1843–1852 (Norfolk Whites 6 years, Swedes 4 years). In Table XLVIII. (p. 159)

is given the produce of barley in 1853, 1854, and 1855, on plots manured for the turnips as under :—

1. A series of plots having various purely mineral manures during the last 8 of the 10 years of the turnips.

2. Plots having the same mineral manures as 1, during the last 8 years, and ammonia-salts (an average of 45 lbs. of nitrogen per acre per annum) during the first 6 of the last 8 years, namely 1845-1850 inclusive.

3. Plots having the same mineral manures during the last 8 years as 1 and 2, and, in addition, an average of nearly 17 cwt.s. rape-cake (= 90 lbs. nitrogen) per acre, per annum, during the first 6 of the last 8 years.

4. Plots having the same mineral manures as 1, 2, and 3, during the last 8 years, and both the ammonia-salts (=45 lbs. nitrogen), and the rape-cake (=90 lbs. nitrogen), per acre, per annum, during the first 6 of the last 8 years.

There is also given in the Table the produce of barley in 1854 and 1855, on—

5. A portion of the previously mineral-manured turnip-land, dressed for the barley-crop of 1854 with ammonia-salts, at the rate of 400 lbs. per acre (= 82 lbs. nitrogen); but without further manure in 1855.

6. Another portion of the previously mineral-manured turnip-land, dressed with nitrate of soda, at the rate of 550 lbs. per acre (= 82 lbs. of nitrogen), for the barley-crop of 1854, and of 112 lbs. (=17 lbs. of nitrogen), for the crop of 1855.

The average produce of turnips over the last 8 years (1845-1852) was :—

	1. With Mineral Manure, alone.		2. With Mineral Manure, and Ammonia-salts.		3. With Mineral Manure, and Rape-cake.		4. With Mineral Manure, Ammonia-salts, and Rape-cake.	
	Tons.	Cwts.	Tons.	Cwts.	Tons.	Cwts.	Tons.	Cwts.
Roots	7	9	10	4 $\frac{1}{2}$	10	19 $\frac{1}{2}$	12	3 $\frac{1}{2}$
Leaves	1	10 $\frac{1}{2}$	3	3	2	13 $\frac{1}{2}$	4	7 $\frac{1}{2}$
Total	8	19 $\frac{1}{2}$	13	7 $\frac{1}{2}$	13	12 $\frac{1}{2}$	16	11 $\frac{1}{2}$

Thus, with purely mineral manures the produce was but small; with mineral manure and ammonia-salts it was more; with mineral manure and rape-cake again rather more; and with mineral manure, ammonia-salts, and rape-cake, together, it was the heaviest, but still, on the average, only about 12 $\frac{1}{2}$ tons of roots, and 4 $\frac{1}{2}$ tons of leaves, per acre per annum. On some portions the mineral manures supplied more of all the mineral constituents than were removed in the turnip-crops, but on others

they did not; yet, there was so little difference in the subsequent produce of barley on the different mineral-manured plots, that only the average of all is given in each case in the Table.

For comparison with the produce of barley after turnips, there is also given in the top line of each division of the Table XLVIII. (p. 159), that without manure in the same seasons (which were the second, third, and fourth of the 20), in the field in which the crop has now been grown for so many years in succession.

The figures show that, over the three years, there were obtained after the mineral-manured turnips, an average of only 20 bushels of barley grain, and not quite 12 cwts. of straw, per acre per annum; or not two-thirds as much as without manure after barley, clover, wheat, barley, and barley, in the same seasons, in the field in which the crop is now being grown continuously.

If, as has been maintained on high authority, the increased produce of corn which is obtained in rotation, is due to the accumulation, or elaboration, during the growth of other crops, of the mineral constituents required for the corn, it might surely be expected that, after a series of mineral-manured turnip-crops, for which, on some of the plots, more of every mineral constituent was supplied in the manure than was taken off in the produce, we should have full crops of barley. But what are the facts? We have after the mineral-manured turnips three perfectly insignificant barley-crops, and much less than when barley was grown after three immediately preceding corn-crops.

The question arises—in what constituent, or constituents, had the mineral-manured turnips so exhausted the soil as to bring it into a condition even far worse for the after growth of barley than when (after clover) three white straw crops had been grown in succession—namely, wheat without manure, barley with sulphate of ammonia, and barley without manure?

It is seen that where, besides the mineral manures, ammonia-salts (experiment 2), rape-cake (experiment 3), and ammonia-salts and rape-cake together (experiment 4), were applied annually during the first 6 of the last 8 years of turnips, there was more produce of barley; both corn and straw, than where the mineral manures had been applied alone; and there was more where rape-cake, or ammonia-salts and rape-cake together, were employed, than where the ammonia-salts without rape-cake were used. The rape-cake not only supplied about twice as much nitrogen per acre as the ammonia-salts, but the nitrogen it contained would exist in a condition both less rapidly available and less liable to loss by drainage. The results obtained after the mineral-manured turnips (experiment 1) exclude the supposition that the increase of produce, where ammonia-salts had also been

TABLE XLVIII.—Three Years of Barley after Ten Years of Turnips.

BARN-FIELD.

PARTICULARS OF MANURES, &c.	PRODUCE OF BARLEY PER ACRE.			
	1853.	1854.	1855.	Average 3 Years
Dressed Corn—Bushels.				
os-Field—				
Barley, without manure, after 3 corn-crops	26	35½	34½	31½
rn-Field—				
Barley, after 10 yrs. Turnips manured as under—				
Mineral manures (last 8 years)	20½	19½	20	20
Mineral manures (8 yrs.); Ammonia-salts (6 yrs.)	23½	21½	21½	22
Mineral manures (8 yrs.); Rape-cake (6 yrs.)	28½	24½	23½	25½
Mineral manures (8 yrs.); Ammonia-salts and Rape-cake (6 yrs.)	29½	23½	23½	25½
Mineral manures (8 yrs.); Ammonia-salts, for Barley, 1854 ..	(20½)	52½	26½	39½
Mineral manures (8 yrs.); Nitrate soda, for Barley, '54 & '55	(20½)	54½	40½	47½

Straw (and Chaff)—Cwts.

os-Field—				
Barley, without manure, after 3 corn-crops	17½	22½	17½	19½
rn-field—				
Barley, after 10 yrs. Turnips manured as under—				
Mineral manures (last 8 years)	12½	12½	10½	11½
Mineral manures (8 yrs.); Ammonia-salts (6 yrs.)	13½	13½	10½	12½
Mineral manures (8 yrs.); Rape-cake (6 yrs.)	17	15½	12½	15½
Mineral manures (8 yrs.); Ammonia-salts and Rape-cake (6 yrs.)	16½	16	11½	14½
Mineral manures (8 yrs.); Ammonia-salts, for Barley, 1854 ..	(12½)	39½	12½	25½
Mineral manures (8 yrs.); Nitrate soda, for Barley '54 & '55 ..	(12½)	42½	22	32½

Total Produce (Corn and Straw)—lbs.

os-Field—				
Barley, without manure after 3 corn-crops	3467	4462	3923	3951
rn-Field—				
Barley, after 10 yrs. Turnips manured as under—				
Mineral manures (last 8 years)	2618	2474	2206	2432
Mineral manures (8 yrs.); Ammonia-salts (6 yrs.)	2864	2691	2331	2629
Mineral manures (8 yrs.); Rape-cake (6 yrs.)	3558	3171	2712	3147
Mineral manures (8 yrs.); Ammonia-salts and Rape-cake (6 yrs.)	3546	3136	2555	3079
Mineral manures (8 yrs.); Ammonia-salts, for Barley, 1854 ..	(2618)	7377	2852	5114
Mineral manures (8 yrs.); Nitrate soda, for Barley, '54 & '55	(2618)	8005	4727	6366

used, was due to any action that they might have in increasing the available supply of mineral constituents within the soil, or that the effects of the residue of rape-cake were attributable to the mineral constituents it supplied. There can, indeed, be no doubt that, in all three experiments, the increased produce of barley was due to an increased supply of available nitrogen within the soil where it had been applied in the manures for the turnips. Still, in neither case is there as much produce of barley as without manure in the other (Hoos) field, where the barley was grown after several previous corn-crops.

But experiments 5 and 6 afford conclusive evidence that it was of available nitrogen for the barley that the soil had become so exhausted by the growth of 10 successive crops of turnips.

Thus, in the second year of barley, 1854, those portions of the mineral-manured turnip-plots which were left without further manure (experiment 1) gave $19\frac{1}{2}$ bushels of corn, and $12\frac{1}{2}$ cwts. of straw, per acre; whilst a portion to which ammonia-salts, at the rate of 400 lbs. per acre, were applied (experiment 5), gave $52\frac{1}{2}$ bushels of corn, and $39\frac{1}{2}$ cwts. of straw; and where 550 lbs. nitrate of soda, containing about the same quantity of nitrogen as the ammonia-salts, was applied (experiment 6), there were obtained $54\frac{1}{2}$ bushels of corn, and $42\frac{1}{2}$ cwts. of straw. In fact, by the simple addition of ammonia-salts or nitrate of soda, from 3 to $3\frac{1}{2}$ times as much total produce (corn and straw together) was grown.

Though not shown in the Table, it may be mentioned as remarkable, that although the produce without manure was very different in the two fields, that obtained when a given amount of nitrogen in the form of ammonia-salts or nitrate of soda was applied was very nearly identical in the different fields. The conclusion is that, in both, the mineral constituents, though abundant, were unavailing in the absence of a sufficiency of available nitrogen, but that when this was superadded, the amount of growth and produce was dependent on the amount of its supply, and the characters of the season.

Lastly, in the third year of barley after turnips (1855), the Plot 5, which had received ammonia-salts in the previous year, gave about $6\frac{1}{2}$ bushels more corn, and $2\frac{1}{2}$ cwts. more straw, than the exclusively mineral-manured plots; and Plot 6, which again received nitrate of soda, but only in small quantity (112 lbs. per acre), gave more than twice as much of both corn and straw as the purely mineral-manured plots.

There is still evidence of another kind, which may be cited as showing that it was of available nitrogen that the turnips had rendered the soil so deficient for the after-growth of barley. It may be assumed that, on the average, between 25 and 30 lbs. of nitrogen would be annually removed from the Rothamsted soil by wheat

or barley grown year after year without nitrogenous manure. But it is estimated that from the mineral-manured turnip-plots there were, over the 10 years, more than 50 lbs. of nitrogen per acre per annum removed. As, however, on some of the plots small quantities of ammonia-salts or rape-cake were applied in the first two years of the ten of turnips, it is, perhaps, more to the purpose to take the average over the last 8 years of turnips only; and this would show about 45 lbs. of nitrogen removed per acre per annum. An immaterial proportion of this might be due to the small amounts of nitrogenous manures applied in the first two years. Still, it may be assumed that about $1\frac{1}{2}$ time as much nitrogen was removed from the land for 8, if not for 10 years, in succession, as would have been taken in an equal number of crops of wheat or barley grown without nitrogenous manure. No wonder, then, that considerably less barley has been grown in 3 years after a series of mineral-manured turnip-crops, than was obtained in another field after a less number of corn-crops.

The results obtained in Barn-field afford a striking illustration of the dependence of the turnip-plant on a supply of available nitrogen within the soil, and of its comparatively great power of exhausting it. They are also perfectly consistent with those in Hoos-field, in showing that mineral manures will not yield fair crops of barley, unless there be, within the soil, a liberal supply of available nitrogen. The results obtained under such very different conditions in the two fields are, in fact, strikingly mutually confirmatory.

2. Barley in Four-Course Rotation of—Turnips, Barley, Clover or Beans, and Wheat—Agdell-Field.

These experiments, which are still in progress, were commenced in 1848, so that the crop of 1871 was the twenty-fourth, and completed the sixth course. The produce of barley obtained in the first three courses was given in the paper above referred to, but it is now given, though in less detail for each course, for the six completed courses.

The area of about $2\frac{1}{2}$ acres was divided into three equal portions. One-third has been left entirely unmanured from the commencement; one-third has been manured with superphosphate of lime* alone, once every 4 years, that is for the turnip-crop

* Quantities per acre, as under—

	Bone-ash.	Sulphuric Acid. (Sp. gr. 1.7).
	lbs.	lbs.
1st Course	100	100
2nd Course	160	120
3rd, 4th, 5th, & 6th Courses ..	200	150

commencing each course; and one-third, also for the turnip-crop only, with a complex manure, consisting of superphosphate of lime, salts of potass, soda, and magnesia, sulphate and muriate of ammonia, and rape-cake.*

From half of each of the three plots the whole turnip-crop (roots and tops) was removed; on the other half the roots were consumed on the land by sheep, and the uneaten leaves spread and ploughed in. In the first course clover was grown as the third crop; but in the second, third, fourth, fifth, and sixth courses, instead of clover, half of each plot was sown with beans, and the other half left fallow.

It would be out of place here, to describe the results obtained in these experiments on rotation, any more than is essential to explain the conditions under which the barley was grown. The results which will be noticed relating to that crop are only those obtained on the portion of each of the three plots from which the turnips were entirely removed, and on which, in the later courses, beans (not fallow) replaced the clover. The facts of chief importance in relation to the other crops are as to the quantity of turnips removed from the land before the growth of the barley. The average produce of turnips per acre over the first five courses (the crop failing in the sixth) was—

	Without Manure.		With Superphosphate alone.		With Mixed Manure.	
	Tons.	Cwts.	Tons.	Cwts.	Tons.	Cwts.
Roots	1	6 $\frac{1}{2}$	6	16 $\frac{1}{2}$	13	2 $\frac{1}{2}$
Leaves	0	10 $\frac{1}{2}$	1	8	2	2 $\frac{1}{2}$
Total	1	17 $\frac{1}{2}$	8	4 $\frac{1}{2}$	14	5

Under each of the three conditions as to manuring, the produce of turnips was much less in the later than in the earlier courses. This was, probably, partly owing to the higher condition of the land, dependent on previous manuring and cropping, at the commencement of the first than of the subsequent courses; but it was partly due to the characters of the seasons. Indeed, in

* Quantities per acre as under—

	Bone-ash.	Sulphuric Acid.	Pearl-ash.	Sulphate Potass.	Sulphate Soda.	Sulphate Magnesia.	Sulphate Ammonia.	Muriate Ammonia.	Rape-cake.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1st Course	100	100	100	..	..	..	100	100	1000
2nd Course	160	120	..	300	100	100	100	100	2000
3rd, 4th, 5th, & 6th Courses	200	150	..	300	200	100	100	100	2000

1868, the first year of the sixth course, turnip-seed was sown twice, but entirely failed, owing to the dryness of the season; and the land was then ploughed up, and left fallow for the barley.

The result in regard to the turnips may be stated in general terms as follows :—

Without manure there was scarcely any produce of turnips at all; there was, therefore, no exhaustion of the land by the removal of the crop; and it was, practically speaking, left fallow for the barley.

With superphosphate of lime alone only small crops of turnips were grown, especially in the later courses; still, much more was removed from the land than without manure; and, as nothing was supplied besides what the superphosphate itself contained, the land was, so far as other constituents are concerned, left in a much more exhausted condition for the growth of the barley than without any manure whatever.

With the mixed manure fair crops of turnips were removed in the earlier, but less in the later courses; and (excepting in the first year) there would remain in the land a considerable residue from the manures applied, and hence it would be left in a higher condition for the barley than after either the unmanured or the superphosphated turnips.

The produce of barley, under each of the three conditions as to manuring for the turnips, in each of the six successive courses, and on the average of the six courses, is given in Table XLIX. (p. 164); and, for comparison, there is also given, in the top line of each division, the produce, without manure, in the same seasons, in the field in which barley is grown year after year on the same land.

It will not be necessary to go into any detail respecting the produce of the individual years any further than to notice the apparently anomalous results of the first year. The much higher produce of barley after the unmanured than after the mixed-manured turnips, may be partly owing to some irregularities in the condition of the land at the commencement; but it is, doubtless, chiefly due to the fact that there had been removed from the unmanured plot only about $3\frac{1}{2}$ tons of roots, and $2\frac{1}{2}$ tons of tops, and from the mixed-manured plot nearly 11 tons of roots, and more than $7\frac{1}{2}$ tons of tops; whilst, as the foot-note at p. 162 will show, the mixed manure was much less liberal for the first than for the subsequent courses. There was, in fact, not only very much more turnips removed from the manured than from the unmanured plot, but there would be much less residue of manurial constituents, if any, left for the barley of the first course, than for that of either of the subsequent courses.

TABLE XLIX.—Barley in Four-course Rotation of—
Turnips, Barley, Clover or Beans, and Wheat.

PARTICULARS OF MANURES, &c.	PRODUCE OF BARLEY PER ACRE.						
	1849.	1853.	1857.	1861.	1865.	1869.	Average.
Dressed Corn—Bushels.							
Hoos-Field— Barley, unmanured, after 3 Corn crops		26	30½	16½	19½	15	21½
Agdell-Field— Barley, in Four-course Rotation—							
Unmanured, continuously	44½	34½	48½	38½	39	24½	36½
Superphosphate, for turnips only	29½	28½	28½	30½	33½	26½	29½
Mixed Manure, for turnips only	28½	38½	48	60½	47½	42½	44½
Straw (and Chaff)—Cwts.							
Hoos-Field— Barley, unmanured, after 3 Corn-crops		17½	14½	10½	8½	10½	12½
Agdell-Field— Barley, in Four-course Rotation—							
Unmanured, continuously	26½	21½	23½	22½	19½	17½	21½
Superphosphate, for turnips only	18½	16½	13½	17½	14½	18½	16½
Mixed Manure, for turnips only	18½	23½	21½	35½	23½	29½	25½
Total Produce (Corn and Straw)—lbs.							
Hoos-Field— Barley, unmanured, after 3 Corn-crops		3467	3295	2107	2042	2016	2565
Agdell-Field— Barley, in Four-course Rotation—							
Unmanured, continuously	5656	4465	5337	4718	4182	3358	4619
Superphosphate, for turnips only	3841	3560	3076	3775	3394	3686	3533
Mixed Manure, for turnips only	3794	4873	5168	7391	5148	5800	5363

It has already been shown that the produce of barley was much less after 10 turnip-crops—the last 8 with mineral manures only—than after 3 preceding corn crops; but, as the top line in each of the divisions of the Table (XLIX.) shows, the produce grown year after year on the same land without manure declined considerably in the later years. It is now seen that the quantity of barley grown in rotation without manure, is very considerably greater than that grown in succession without manure. The produce is, indeed, considerably higher when grown in rotation after unmanured, than after superphosphated turnips. This is accounted for by the fact already stated, namely, that as scarcely any turnips were removed from the unmanured plot, the land

was practically left fallow for the barley; whilst, from the superphosphated plot, the quantity removed would considerably exhaust the land.* Again (omitting the first year), the produce after the removal of the full-manured and larger crops of turnips was uniformly, and on the average, very much higher than after the removed superphosphated turnips, and also generally, and on the average, higher than after the unmanured turnips. This larger produce of barley after the removal of the larger crops of turnips grown by the mixed manure, is doubtless due to the fact that there would still be a considerable residue of the manure left within the soil.

It has already been shown, both by the results of the growth of barley year after year on the same land, and by those of its growth after the removal of a series of mineral-manured turnip-crops, that a liberal supply of mineral constituents alone is insufficient to secure a fair crop of barley. In both sets of experiments it was also shown that the further addition of nitrogenous manure raised the produce to a maximum. It might safely be concluded, therefore, that the larger produce of barley after the full manured, than after the superphosphated or the unmanured turnips in rotation, was not attributable to any residue of mineral constituents alone which would be left after the removal of the highly manured roots; and that the larger produce after the unmanured than after the superphosphated turnips was not due to a less exhaustion or greater accumulation of available mineral constituents where the smaller crop of turnips was removed.

But other evidence is not wanting to confirm the conclusion that the higher produce of barley after the unmanured than after the superphosphated turnips in rotation, and the higher produce still after the full-manured than after the unmanured turnips, were each due, in great part, to an accumulation of available nitrogen within the soil for the barley. Thus, it is estimated that, from the superphosphated plot, which yielded the smallest produce of barley, the turnips would probably, on the average of the five seasons in which they grew, remove about 50 lbs. of nitrogen per acre, or more than would be supplied in 200 lbs. ammonia-salts. From the unmanured plot they would remove only from one-fourth to one-third as much; and much less than would be contained in the increased produce of a corn-crop that would result from the fallowing of the land; so that, presumably, there would remain a considerable available store for the barley. From the mixed-manured plot, again, though the turnip-crop of the first course most probably removed considerably more

* The larger produce of barley on the superphosphated than on the unmanured plot in 1869 is only apparently an exception; for, as has been stated, the turnips failed in 1868, and there was, therefore, nothing removed from either plot in that year.

nitrogen than was supplied in the manure, the average produce of the subsequent courses would appear, by calculation, to have removed much less than was supplied; and, as most of that which was supplied was in the form of rape-cake, there would doubtless be an effective residue left within the soil.

To sum up the results on the point:—As in other experiments, so also in these, in which barley was grown in rotation, and under three very different conditions as to manuring, the evidence is sufficiently conclusive, and, therefore, corroborative of that in the other cases, that an essential condition for the growth of a full crop of barley, whether in rotation, or under less usual conditions, is a liberal supply of available nitrogen within the soil.

SECTION VI.—SUMMARY AND GENERAL CONCLUSIONS, SHOWING THE PRACTICAL BEARINGS OF THE RESULTS.

In a former paper it was shown, that wheat had been successfully grown for twenty years in succession on the same land; that the produce without manure had, during that period, diminished comparatively little; and that that by farmyard manure, and by certain artificial manures, had increased considerably. The thirtieth wheat crop is now growing, and shows no deterioration, in either quantity or quality, where the proper manures, natural or artificial, have been supplied. The most prominent result was, and still is, that mineral manures alone increase the produce scarcely at all; that nitrogenous manures alone increase it very considerably; but that the largest crops are obtained when nitrogenous and mineral manures are applied together.

How far do the results now recorded in regard to *barley* accord with those which have been obtained with its botanical ally—wheat?

The results on the growth of barley, without manure, by farmyard manure, and by a great variety of artificial mixtures, each used for twenty years in succession on the same land, have been given in detail in the foregoing pages; and they have been compared with those obtained with wheat under corresponding conditions. They have been classified, and given in separate sections, and at the conclusion of the sections they have been more or less formally summarised. It remains to call attention here to the most prominent results of the inquiry as a whole, with as little reference to detail as may be consistent with clearness, referring the reader to the detailed discussion of individual points, and to the summaries, given at the conclusion of preceding sections, for any further illustration or confirmation that may be needed.

The twenty-second crop of barley in succession is now growing, in a field immediately adjoining that devoted to the experiments on wheat, and having a soil and subsoil of similar general characters, namely, "a somewhat heavy loam, with a subsoil of raw yellowish-red clay, but resting in its turn upon chalk, which provides good natural drainage." It is obvious that, in wet seasons, such a soil is not well suited for the growth of the crop after roots fed on the land by sheep, as is the custom of the locality; but, the results which have been recorded abundantly prove that, when grown under favourable conditions, large crops of barley, of good quality, may be obtained from such land.

Without manure, the average produce of barley, over twenty years, was 21 bushels of dressed corn, of $52\frac{1}{2}$ lbs. per bushel, and 12 cwt. of straw. The quantity fell off considerably, but the quality was considerably higher over the second than over the first ten years. Compared with wheat without manure, barley gave more corn, less straw, but nearly the same quantity of total produce; it, however, fell off more in produce of grain, and about equally in straw, over the later years.

By Farmyard manure, the average annual produce was more than 48 bushels of dressed corn, of $54\frac{1}{3}$ lbs. per bushel, and 28 cwt. of straw. The quantity of both grain and straw, and the quality of the grain, were considerably higher over the second than over the first ten years. As without manure, so with farmyard manure, barley, compared with wheat, yielded more corn, less straw, but much about the same quantity of total produce.

Mineral manures alone gave very poor crops; and the quantity of both corn and straw fell off considerably during the later years. With barley there was much more grain, rather less straw, but considerably more total produce than with wheat.

Nitrogenous manures alone gave much more barley than mineral manures alone; the produce declined much less in the later years; and, for twenty years in succession, fair, though not full, crops were obtained.

Nitrogenous and mineral manures together gave, for twenty years in succession on the same land, rather more of both corn and straw than farmyard manure, considerably more than the average barley crop of the country under rotation, and an average weight per bushel of between 53 and 54 lbs. With the same amount of nitrogen, and the same mineral manure, applied for twenty years, in the autumn for wheat, and in the spring for barley, the barley gave much more corn, more straw, and nearly one-third more total produce than the wheat.

Thus, then, with barley as with wheat, mineral manures alone failed to enable the plant to obtain sufficient nitrogen and carbon to yield even a fair crop. The greater effect of nitrogenous manures alone showed that the soil, in its practically

corn-exhausted condition, was relatively richer in available mineral constituents than in available nitrogen. And the generally greater effect by nitrogenous and mineral manures together, than by farmyard manure—which contained not only very much more nitrogen, but a large amount of decomposing carbonaceous organic matter, and probably more of every mineral constituent than the crop—showed that the nitrogen of the farmyard manure was in a far less rapidly available condition, and that its supply of carbon was at any rate unessential.

It is hardly necessary to add, that the field results with barley, equally with those with wheat, are entirely inconsistent with the *mineral theory* so long in controversy, according to which—fertility was quite independent of the ammonia conveyed to the soil;—if only the necessary mineral constituents were supplied in sufficient quantity and in available form, our cultivated plants, graminaceous as well as leguminous, would derive sufficient ammonia from the atmosphere;—the presence of ammonia in our manures was immaterial; and—the entire future prospects of agriculture depended upon our being able to dispense with ammonia in our manures, therefore with animal manures.*

It is a very remarkable and very significant fact, that not only by farmyard manure, but also by artificial manures containing no carbon, an average of not far short of 50 bushels of barley-grain (or more if reckoned at only 52 lbs. per bushel), and nearly 30 cwts. of straw, or much more than the average crop of the country under rotation, should have been obtained by the growth of the crop year after year on the same land for twenty years in succession. Not only was such an average obtained over the twenty years, but there was even rather more corn, higher quality, only little less straw, and nearly identical total produce (corn and straw together), over the second compared with the first ten years, showing that, hitherto at least, there is practically no exhaustion by the continuous growth of such large crops under such conditions of soil and manuring.

It was with farmyard manure, however, the annual use of which has resulted in a very great accumulation within the soil, of nitrogen, of carbon, and probably of every mineral constituent also, that there has been the greatest increase of produce, and especially of corn, over the second as compared with the first ten years. On the other hand, without manure, with mineral manure alone, and with ammonia-salts alone—that is, with defective soil conditions—there was a considerable deficiency of both corn and straw over the second half of the period; the greater deficiency the more defective the manuring, and the greater the relative

* For further remarks on the present position of the mineral theory controversy, see pp. 6-7 and 14-16.

deficiency of nitrogen in the soil; for the falling off was considerably more marked with mineral manure alone, than with ammonia-salts alone.

It will be obvious that an average of 50 bushels of barley-grain, and 30 cwt. of straw, would not be maintained without great fluctuations from year to year, according to season. Indeed, in no two years of the twenty did one and the same manure yield precisely the same result both as to the quantity and the quality of its produce; nor were the seasons which were more or less favourable than the average for one description of manure equally favourable for other descriptions. Thus, comparing the least and the most productive seasons of the twenty, there were obtained (reckoning the total corn at 52 lbs. per bushel)—without manure $15\frac{1}{2}$ and $37\frac{1}{2}$ bushels, or a difference of 22 bushels; with farmyard manure, 32 bushels and 60 bushels, or a difference of 28 bushels: lastly, with the two most productive artificial manures, there were obtained $30\frac{1}{2}$ and $36\frac{1}{2}$ bushels in the worst season, and 66 and 68 bushels in the best season, or a difference in favour of the good season of $35\frac{1}{2}$ and $31\frac{1}{2}$ bushels of grain. That is to say, with one and the same expenditure for manure, there was a difference in the quantity of the produce obtained in the two seasons, of from nearly 32 to over 35 bushels of corn, besides, in one case, nearly a ton of straw.

Not only, then, has the average produce over twenty years, by artificial, nitrogenous and mineral, manures, considerably exceeded the average barley crop of the country with rotation, but the difference between the produce by one and the same manure in the least and the most favourable seasons of the twenty was, itself, not much less than would represent the average barley crop of many localities.

As we have in substance frequently said, it is but a truism to assert that the growing plant must have within its reach a sufficiency of the mineral constituents of which it is to be built up. But the results obtained with barley, as well as those with wheat, have shown that, whilst it is essential that there be a liberal provision of mineral constituents within the soil, the amount of produce is more dependent on the supply by manure of available nitrogen than of any other constituent.

The practical question obviously arises—How much ammonia, or its equivalent of nitrogen in some other form, will, on the average, be required to yield a given amount of increase of wheat or barley grain, and its proportion of straw?

In our Report on the growth of wheat for twenty years in succession on the same land, it was shown that the quantity of increase obtained for a given amount of ammonia, or its equivalent of nitrogen, in manure, varied exceedingly according to the amount applied, to the provision of mineral constituents within

the soil, and to the seasons. It was, however, stated, as a general practical conclusion, that, under the conditions the most comparable with those of ordinary practice, approximately 5 lbs. of ammonia, or its equivalent of nitrogen, were, on the average, required to yield 1 bushel increase of wheat, and its proportion of straw.

In like manner the experiments with barley have shown a very wide variation in the amount of ammonia required to yield a given quantity of increase, according to the amount applied, to the provision of mineral constituents within the soil, and to the seasons.

Thus, with superphosphate and 200 lbs. of ammonia-salts per acre per annum, for six years, 3.26 lbs., but with 400 lbs. 5.06 lbs. of ammonia were required to produce 1 bushel increase of barley-grain and its straw.

Again, with 200 lbs. of ammonia-salts for twenty years, there were required—on three plots where it was used with superphosphate 2.13, 2.41, and 2.10 lbs.; on one plot where it was used with salts of potash, soda, and magnesia, without superphosphate, 3.59 lbs.; and on one without any mineral manure at all, 3.68 lbs. of ammonia to yield 1 bushel of barley and its straw.

Lastly, with only 200 lbs. of ammonia-salts per acre per annum, and with superphosphate also applied, the difference in the amount of ammonia required to yield 1 bushel of increase was, according to season, from about $1\frac{1}{2}$ lb. in the two most favourable, to 5.36 and 4.48 lbs. in the two least favourable seasons; whilst, with only the same moderate amount of ammonia-salts, but used without superphosphate, or without any mineral manure at all, the difference in result according to season was very much greater still.

Notwithstanding these very considerable, and very significant variations, it may be concluded, from a review of the whole of the data bearing on the point, that when an increase of barley is obtained by means of artificial manures, such as salts of ammonia, nitrate of soda, or Peruvian guano, an increase of 1 bushel of grain, and its straw, may, taking the average of seasons, be calculated upon for every 2 to $2\frac{1}{4}$ lbs. of ammonia (or its equivalent of nitrogen, 1.65 to 1.86 lbs.) supplied in the manure—provided the quantity applied be not excessive, and there be no deficiency of mineral constituents within the soil. When, however, rape-cake is used, rather more nitrogen in that form will be required to yield a given increase; but when the increase is obtained by sheep-folding, or by farmyard manure, very much less increase will be yielded in the year of the application, in proportion to the nitrogen contained in the manure.

Thus, whilst it was concluded that, on the average, about 5 lbs. of ammonia (or its equivalent of nitrogen) were required to yield 1 bushel of increase of wheat, and its proportion of straw, it is now assumed that only 2 to $2\frac{1}{4}$ lbs. of ammonia are

required to produce 1 bushel increase of barley, and its straw. But whilst an average bushel of wheat may be reckoned to weigh 61 lbs., and its average proportion of straw 105 lbs., an average bushel of barley will weigh only 52 lbs., and its straw only 63 lbs. Hence, whilst it required 5 lbs. of ammonia in manure to yield 61 lbs. of wheat-grain, and 105 lbs. of straw = 166 lbs. of total produce, it only requires from 2 to $2\frac{1}{2}$ lbs. to yield 52 lbs. of barley-grain and 63 lbs. of straw = 115 lbs. of total produce. In other words, for the production of 100 lbs. increase of total produce of wheat, it required 3 lbs., and for the production of 100 lbs. increase of barley (containing a larger proportion of grain, but about the same amount of nitrogen) it required only from about $1\frac{1}{2}$ to 2 lbs. of ammonia in manure. That is to say, it required much more ammonia to yield a given amount of increase when applied in the autumn for wheat, than when in the spring for barley.

The following questions obviously suggest themselves :—

What proportion of the nitrogen supplied in manure will probably, on the average, be recovered in the increase of the crop for which it is applied?

Will the at first unrecovered amount have any marked effect on the immediately or early succeeding crops?

Will there be any residue retained by the soil and the subsoil, in such a state of combination, and distribution, as only to be yielded up, if ever, in the course of a long series of years?

Will there be any drained away and lost?

Lastly, will the answers arrived at on these points, in regard to wheat or to barley, be equally applicable to both crops?

With regard to the proportion of the nitrogen of artificial manures recovered in the increase of crop obtained by their use, in former papers it has been estimated, taking the average over a comparatively limited number of years, that about 40 per cent. was recovered in the increase of wheat, of barley, and of meadow-hay indifferently. But, by the aid of numerous new determinations of nitrogen in the produce of wheat for twenty years, of barley for twenty years, and of oats for three years, it now appears that, with the same mixed mineral manure in each case, and the same amount of ammonia-salts applied in the autumn for wheat, and in the spring for barley and for oats, rather less than one-third of the supplied nitrogen has been recovered in the increase of the wheat, but nearly one-half in that of the barley and the oats. When, however, there were applied, even for wheat, the same mineral manure and nitrate of soda, the latter sown in the spring, a not much less proportion of its nitrogen was recovered in the increase of the crop, than in the case of the ammonia-salts applied for barley in the spring, or of the ammonia-salts or nitrate of soda applied for oats in the spring.

Not only, then, did a given amount of nitrogen, supplied as ammonia-salts, yield much more increase of produce in the years of its application, when applied in the spring for barley than when in the autumn for wheat, but a larger proportion of it was recovered in the increase of the spring-sown crop.

The field experiments have further shown, that the at first unrecovered amount yielded scarcely any increase at all in succeeding years in the case of the wheat, but a considerable increase in that of the barley.

With both crops, however, there remained a considerable amount of the supplied nitrogen not recovered in either the at first, or the early succeeding, increase of produce; but there is obviously very much more to be otherwise accounted for in the case of the autumn-sown wheat than of the spring-sown barley.

With regard to retention by the soil, the results of the analysis of samples of the soils of many of the differently manured plots in the experimental wheat-field, taken in all down to a depth of 27 inches, showed that a considerable amount of the nitrogen which had been supplied in the manure, and not recovered in the increase of crop, was accumulated within the soil; but it was concluded that a larger proportion remained unaccounted for to the depth examined, than was there traceable, and that some of this had passed off by the drains, and some into the lower strata of the subsoil.

With regard to loss by drainage, numerous analyses, by Dr. Voelcker and Dr. Frankland, of the drainage waters from the Rothamsted experimental wheat-plots, confirmed the supposition that there had been a considerable loss of the nitrogen of the manures in that way. They showed that the quantity of nitrates in the drainage-water was the greater the greater the amount of ammonia-salts applied; and that, after autumn-sowing, the quantity was very much greater in the winter than subsequently in the spring and summer.

Calculation showed that, for every 1 part of combined nitrogen per 100,000 parts of drainage-water, there will be a loss of $2\frac{1}{2}$ lbs. of nitrogen per acre for every inch of rain passing beyond the reach of the roots as drainage of that strength. In one case of winter-drainage, after an application of 600 lbs. of ammonia-salts per acre in the autumn, Dr. Frankland's analysis showed 7.841 parts of nitrogen per 100,000 parts of water, corresponding to a loss of nearly 18 lbs. of nitrogen per acre, provided (which, however, is not probable) that an inch of rain had passed as drainage of that strength.

As would be expected, as the nitrate of soda was, even for wheat, always sown in the spring, the autumn and winter-drainage from the nitrated plot always contained much less nitrogen than that collected at the same date from the plots

manured with ammonia-salts in the autumn. Owing, however, to the much less capacity of a given surface of soil for the absorption of nitrate of soda, or other nitrates arising from its decomposition, than of the ammonia of ammonia-salts, heavy rains, soon after sowing, would carry off more of the nitrogen from nitrate of soda than from a corresponding dressing of ammonia-salts. In one case Dr. Voelcker found, in the drainage collected from the nitrated plot soon after a dressing of 550 lbs. of nitrate per acre (= 400 lbs. ammonia-salts), applied in the spring, 5.83 parts of nitrogen per 100,000 parts of water, corresponding to a loss of about 13 lbs. of nitrogen per acre per inch of rain passing.

These facts, showing how great may be the loss of the nitrogen of manure by drainage, are obviously of the greatest practical importance, and demand very serious consideration.

Owing to the difficulty of determining with certainty, either the total amount of nitrogen retained by the soil within the reach of the roots, the proportion of the total rain which would pass beyond the reach of the roots, or the *average* composition of the drainage-water, absolute proof whether the whole of the supplied nitrogen which is not recovered in the crop is either retained by the soil, or lost by drainage, is not at command. Still, a consideration of such data as are available in reference to the points here indicated, points to the conclusion that the whole of the nitrogen which was applied as ammonia-salts or nitrate of soda to the wheat was either *recovered in the increase of crop, accumulated within the soil, or lost by drainage.*

As already said, as the proportion of the nitrogen of ammonia-salts which was recovered in the increase of produce was much greater in the experiments with barley than in those with wheat, there remained of course much less, in its case, to be accounted for by accumulation in the soil, and by drainage.

Only few determinations of nitrogen have as yet been made in the soils of the barley plots; but, so far as can be judged from the results obtained hitherto, it seems probable that there is less accumulation than in the case of the wheat, especially in the lower layers. It seems pretty certain, too, that there must be much less loss by drainage; but, as the experimental barley-field is not artificially drained, no direct evidence can be adduced on the point. It may be observed, however, that as the ammonia-salts are sown for the barley in the spring, when the soil is in a porous condition, when there is comparatively little risk of washing out, and when growth almost immediately succeeds, there will be a less immediate and wide distribution of the ammonia, or of the nitrate resulting from its oxidation, a larger proportion at once taken up by the growing crop, and, probably, a larger proportion fixed near the surface before the winter-rains, and remaining available there for succeeding crops.

Not only, then, do the results point to a satisfactory explanation of the loss of nitrogen which has been observed in the use of artificial nitrogenous manures, but also of the much greater loss when they are applied in the autumn for wheat, than when in the spring for barley or for oats. In confirmation of the explanation on the latter point, may be cited the facts that, not only was there on the average much more increase even of wheat, and much more nitrogen recovered in the increase, when a given amount of it was applied as nitrate of soda in the spring than when as ammonia-salts in the autumn, but the difference in favour of the spring-sown manure was especially marked after unusually wet autumns and winters.

There is another point to notice in connection with the action of nitrate of soda. A given surface of soil has much less power to retain either nitrate of soda, or other nitrates, than ammonia, and so far their nitrogen is, *cæteris paribus*, more liable to loss by drainage. Yet, when frequently used on the same land, such was the effect of the nitrate, or its products of decomposition, aided by increased development of root, in causing the disintegration, and so increasing the porosity and surface of the clay subsoil, that there would appear to have been not only a greater retention of moisture in an available form by the subsoil, rendering the growing crop more independent of drought, but also a greater retention of nitrates than would be anticipated considering their solubility, and, hence, a more lasting effect from previous applications than would otherwise be expected. On the other hand, where, as in the case of the experiments at Rothamsted, nitrate of soda has been used in large quantities so many years in succession, the surface soil has retained so much moisture as to be difficult to work after wet weather.

The results have shown, that a considerably less proportion of the nitrogen applied as rape-cake, than as either ammonia-salts or nitrate of soda, was recovered in the increase of crop within a given period of time, and again considerably less of that applied in farmyard manure than in rape-cake. Owing to the slow decomposition of the nitrogenous organic matter of these manures, their nitrogen is necessarily but slowly available. It would appear, however, to be, at the same time, less subject to loss by drainage; and analysis has shown that a large proportion of their nitrogen is retained by the soil, becoming but very gradually available for a considerable length of time. Indeed, analysis showed that where farmyard manure had been applied for wheat every year for twenty-five years in succession, the top 9 inches of soil contained nearly twice as high a percentage of nitrogen as the corresponding layers of any of the artificially manured plots, which, though they received much less nitrogen annually, as ammonia-salts or nitrate of soda,

nevertheless yielded larger crops. Still, there is a large amount of the nitrogen of the dung not yet satisfactorily accounted for; but, whether there will be an ultimate loss of a greater or less proportion of that supplied, than when ammonia-salts or nitrate of soda is used, the data at present at command do not enable us to determine with certainty.

It is, then, established, that there is a great liability to loss by drainage of the nitrogen of manures, the available amount of which, more than of any other constituent, rules the amount of produce, under the existing conditions of British agriculture. The mineral constituents being, however, equally essential for growth, it is obviously important to have some direct experimental evidence showing whether or not they are also liable to such loss.

The field experiments with wheat have afforded conclusive evidence of the marked effect of potass and phosphoric acid supplied more than twenty years previously, when nitrogenous manures were afterwards applied to render them available; and, not only are the results of the analysis of the produce consistent with this, but the analysis of the soils has shown their accumulation, and that of the drainage-waters their comparatively little liability to loss in that way. Indeed, it may be concluded that, at any rate in the case of the heavier soils, these constituents, which, by the sale of corn and meat, would otherwise be the most likely to become relatively deficient, and which in that point of view are the most important to consider, are almost wholly retained within the reach of the roots.

Let it be granted—that, in one field at Rothamsted, wheat, and in another barley, have been grown for many years in succession, the same manure being applied to the same plot year after year; that, under these circumstances, it has been found that mineral manures alone have little or no effect, that nitrogenous manures alone have very much more, and that nitrogenous and mineral manures together will continue to yield as large crops as farmyard manure annually applied, and much larger than the average produce of the country under rotation. It may still be asked, whether conclusions drawn from results obtained under such unusual conditions may be trusted as any guide to the requirements of the crops when grown on any other land, or in the ordinary course of farming?

In our paper on the growth of wheat for twenty years in succession on the same land ('Journal of the Royal Agricultural Society of England,' vol. xxv., pp. 491–494), we adduced the results of direct experiments, made not only in another field at Rothamsted, but also in other localities, on soils of very different description, and in very different condition. The result in each

case was, as in the experimental field, that there was but little increase by mineral manures alone, much more by ammonia-salts alone, and more still by ammonia-salts and mineral manure together. We further stated our conviction, founded on a very extensive acquaintance with the practical experience of farmers in the use of artificial manures in every district of Great Britain for many years, that, in 99 cases out of 100 in which wheat is grown in the ordinary course of agriculture with rotation, the supply of immediately available mineral constituents is in excess relatively to the immediately available supply of nitrogen.

In our former paper on the growth of barley, and again in Section V. of the present paper, evidence of a similar kind is adduced in regard to that crop. Two sets of experiments are quoted. In one, barley was grown for three years in succession on a series of plots which had previously been differently manured, and grown ten crops of turnips in succession. In the other, it was grown in four-course rotation, without manure, and with different descriptions of manure. The evidence of these other experiments is entirely confirmatory of the conclusion,—that mineral manures alone will not yield fair crops of barley, and that an essential condition for the growth of full crops, whether in rotation or under less usual conditions, is a liberal supply of *available nitrogen within the soil*.

Further, as in the case of wheat, so also in that of barley, the common experience of the country at large, in the use of artificial manures to that crop, is entirely confirmatory of the conclusions to which the results of the experiments on its growth year after year on the same land would lead.

It may here be remarked, that the greater liability to loss by drainage of the nitrogen, than of the more important mineral constituents of manure, is doubtless one element in the explanation of the fact of the prevailing excess of available mineral constituents, relatively to available nitrogen, in soils generally, under the ordinary course of agriculture in this country.

Those who have examined for themselves the evidence that has been adduced, and carefully considered the conclusions that have been drawn, in reference to the great number of points which this enquiry has opened up, will probably feel that they do not require any specific receipts to be laid down for their guidance, and that they will profit more by the direction which the study of the facts must give, to their own observation and reflections on what comes before them in the course of their daily experience. Indeed, under any circumstances, it must be left to the intelligence and the judgment of the individual farmer to decide upon the degree in which any special recommendations will be applicable to his own particular soil, and other circumstances.

Still, in bringing this long report to a conclusion, a few words should be offered by way of pointing out the more directly practical application of the results.

For twenty years in succession on the same land, an annual expenditure of less than 3*l.* per acre in artificial manures has yielded an average produce of 6 quarters of dressed barley, of good quality, and nearly 1½ ton of straw. Any practical farmer can estimate what would be the additional expense upon the crop, in the way of rent, cultivation, harvesting, bringing to market, &c.; and, having done so, the result will doubtless show a considerable profit.

The soil at Rothamsted is more suitable for wheat than it is for the growth of barley after roots, as is the common practice of the locality; but, the facts show that it will nevertheless grow large crops, of good quality, under favourable circumstances. Indeed, it may be laid down as a general rule, applicable to the country at large, that, on the heavier soils, full crops of barley, of good quality, may be grown with great certainty after a preceding corn crop, under the following conditions:—

First of all, it is essential that the land be got into good tilth. It should be ploughed up when dry, as soon as practicable after the removal of the preceding crop. In the spring it should be prepared for sowing, by ploughing or scuffling, as early in March as possible, if sufficiently dry.

The artificial manure employed should contain nitrogen, as ammonia or nitrate (or organic matter), and phosphates.

From 40 to 50 lbs. of ammonia (or its equivalent of nitrogen as nitrate) should be applied per acre. These quantities would be supplied in—

1½ to 2 cwts. of sulphate ammonia, or—

1½ to 2½ cwts. of nitrate of soda.

With either of these there should be employed—

2 to 3 cwts. mineral superphosphate of lime.

Of late years the composition of Peruvian guano has been so variable and uncertain, that it is quite impossible to estimate how much of it would be required to supply nitrogen equal to from 40 to 50 lbs. of ammonia. It is impossible, therefore, under such circumstances, to recommend it. If, however, the agents of the Peruvian Government manufacture their guano into a substance of uniform quality, and will guarantee to deliver it of a stated composition, it would be quite otherwise; and, as the guano itself contains phosphates, if the ammonia required were purchased in that form, superphosphate need not be also employed.

Rape-cake is also a good manure for barley. From 6 to 8 cwts. would supply about as much nitrogen as would be equal to from 40 to 50 lbs. of ammonia. But, a smaller proportion of the

nitrogen of rape-cake, than of sulphate of ammonia, nitrate of soda, or Peruvian guano, will be effective within a given time. In the experiments at Rothamsted about 9 cwt. of rape-cake per acre per annum, gave an average annual produce, over 14 years in succession, of 44 bushels of dressed corn, of nearly 55 lbs per bushel. With rape-cake, as with guano, the addition of superphosphate is unnecessary.

Whatever manure be used, it should be broken up, finely sifted, sown broadcast, and harrowed in with the seed.

Economy in the cost of the nitrogen is the essential point to be considered in the selection of the manure to be used. To enable the farmer to make an advantageous choice, according to the market price of the different manures at the time, it may be useful to state, as a basis of the calculation, that 1 cwt. of nitrate of soda, of the quality usually imported, contains nitrogen equal to 21 lbs. of ammonia; and if the nitrate cost 15s. 9d. per cwt., that will be equivalent to 9d. per lb. for ammonia, or 15s. per ton for every 1 per cent. of ammonia (or nitrogen equal ammonia) which the manure contains. According to the experiments at Rothamsted, it would appear that, at equivalent prices, a given amount of nitrogen as nitrate of soda may, in the long run, be more effective than an equal amount as ammonia; for, contrary to the current opinion, the full effect of the nitrate was not obtained until it had been used for some years on the same plot.

The liability to loss of the nitrogen of manure by drainage has been shown to be very great. It will, of course, vary very much, according to the characters of the soil and subsoil, and of the seasons. But as it is much greater during the late autumn and winter months, than in the spring and summer, nitrate of soda, sulphate of ammonia, or Peruvian guano, should always be sown in the spring;—for wheat as a top-dressing in March, and for barley, or oats, as described above.

By a more liberal application of manure per acre for the root-crop, the area devoted to it may be considerably reduced with comparatively little reduction in the amount of the crop on the farm as a whole. Barley might then be grown more frequently, with an increase of profit to the cultivator, and without lessening the renting value of the land.

Rothamsted, July, 1873.

APPENDIX-TABLES.

of Barley,

on the same LAND, with

APPENDIX-TABLE II. Description, or quantity, of Manure

1859.	1860.	1861.	1862.	1863.
Bushels.	Busbels.	Busbels.	Busbels.	Busbels.
13½	13½	16½	16½	22½
19½	15½	25	21½	32½
15½	15½	18½	19½	27½
19½	18½	29½	25½	33
17½	15½	22½	20½	26½
15½	26½	30½	31½	45½
34½	43½	55	48½	61½
16½	28	32½	35½	46½
34½	43½	54½	47½	55½
25½	35½	43½	40½	52½
21½	25½	35	31½	49
35½	43½	55½	51	60½
20½	30½	36½	36½	56
35½	46½	55½	48½	59½
28½	36½	45½	41½	53½
38½	31½	56½	41	51½
41	36½	56½	45	55
34½	35½	51½	36	53½
35	40½	53½	45½	54½
37½	36½	54½	41½	59½
24½	27½	38½	35½	51½
26½	29½	41½	38½	55½
19½	10½	27½	23½	26½
16½	10½	28½	17½	29½
33½	39	49½	46½	51½
17½	12½	16½	18½	27½
14½	12½	17½	19	26½
40	41½	54½	49½	59½

of 9 years (1853-'61), last 10 years
(*) Averages of 9 years (1853-'61).

MANURE, and with different descriptions of MANURE. Hoos Field, Rothamsted.

bush per Acre—Bushels.

the period indicated, for particulars of which see *Appendix-Table I.*, and sides-notes thereto, p. 179.]

HARVESTS.								AVERAGE ANNUAL.			PLOTS.
1864.	1865.	1866.	1867.	1868.	1869.	1870.	1871.	First 10 Years, 1852-'61	Second 10 Years, 1862-'71.	Total Period, 20 Years, 1852-'71.	
Busbels.	Busbels.	Busbels.	Busbels.	Busbels.	Busbels.	Busbels.	Busbels.	Busbels.	Busbels.	Busbels.	
24	18	15½	17½	15½	15½	13½	16½	22½	17½	20	1 O.
30½	22½	22½	24½	18½	18½	18	23½	27½	23½	25½	2 O.
26½	22	19½	17	14½	18½	16½	19½	24½	20½	22½	3 O.
33½	24½	24	20½	17½	22½	18½	25	30½	24½	27½	4 O.
28½	21½	20½	19½	16½	18½	16½	21½	26½	21½	23½	Means
35½	29½	27½	30½	20½	27½	27½	36½	33½	31½	32½	1 A.
58½	48½	50½	44	37½	48	41½	45½	45½	48½	47	2 A.
43½	33½	27½	33	25	34½	30½	38½	35	35	35	3 A.
55½	46½	47	43½	34½	49½	38	46½	46½	46½	46½	4 A.
49½	39½	38½	37½	29½	39½	34½	41½	40½	40½	40½	Means
41½	33½	29½	29½	27	32½	29½	39½	39½	34½	37	1 AA.
56½	47½	50½	44½	44	48½	46½	46½	48½	49½	49½	2 AA.
44½	34½	29½	32½	27½	33½	32½	36½	38½	36½	37½	3 AA.
56½	48½	50½	45	45½	49½	44½	46	49½	49½	49½	4 AA.
49½	41½	40½	38	36	41	38½	42	44½	42½	43½	Means
44½	34½	37½	32½	29½	34½	35	44½	(1) 37½	36½	37	1 AAS.
54½	47½	51½	44	44	49	44½	49½	(1) 49½	47½	48½	2 AAS.
50	41	41½	39½	36½	40½	42½	48½	(1) 43½	42	42½	3 AAS.
59½	50½	50½	45½	46½	51½	47½	48½	(1) 51½	48½	50	4 AAS.
52	43½	45½	40½	39½	44½	42½	48½	45½	43½	44½	Means
48½	45	45½	38½	37	42½	41½	44	47	43½	45½	1 C.
51½	46½	47½	45½	35½	48½	41½	41½	47½	45½	46½	2 C.
49½	48½	48½	38½	35½	43½	38½	45½	44	43½	43½	3 C.
53	48½	48½	42½	36½	52½	43½	47½	47½	47½	47½	4 C.
50½	47	46½	41½	35½	46½	41½	44½	46½	45	45½	Means
40½	37	34½	33	25½	35½	34½	43½	(2) 37½	37½	37½	1 N.
46½	39½	41	36½	25½	38½	40½	45½	(2) 42½	40½	41½	2 N.
25½	19½	19	20½	14½	16½	16½	22½	(3) 22½	20½	21½	M.
26½	23	22½	19½	15	23½	14½	20	(4) 24½	21½	22½	5 O.
50½	48½	48½	34½	36½	49½	41½	44½	43½	44½	44½	5 A.
25½	21	16½	16½	15½	14½	15½	18½	25	18½	22	1) 6
25½	19½	17½	19½	15½	15½	15½	24½	23½	20	21½	2) 6
62	52½	53½	45½	43½	46½	47½	54½	45	51½	48½	7

and total 19 years.

(3) Averages of 7 years (1855-'61), last 10 years, and total 17 years.

last 10 years, and total 19 years.

EXPERIMENTS ON THE GROWTH OF BARLEY year after year on the same LAND, without

APPENDIX-TABLE III. *Wheat*

[N.B. The double vertical lines show that there was a change in the description, or quantity, of Manure]

PLOTS.	HARVESTS.											
	1852.	1853.	1854.	1855.	1856.	1857.	1858.	1859.	1860.	1861.	1862.	1863.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1 O.	52.1	51.4	53.6	52.4	49.1	52.0	53.0	49.0	50.8	52.3	50.3	53.6
2 O.	52.6	52.6	54.0	52.5	46.5	52.8	54.0	52.0	50.5	53.3	52.0	54.2
3 O.	52.5	51.9	53.6	52.9	48.5	52.5	53.5	49.5	50.3	52.8	51.8	54.5
4 O.	51.5	52.1	54.0	53.1	47.0	53.7	54.0	52.5	51.3	54.0	52.0	54.8
Means	52.2	52.0	53.8	52.7	47.8	52.8	53.6	50.8	50.7	53.1	51.5	54.3
1 A.	50.7	52.4	53.6	51.8	48.5	51.9	53.0	47.5	50.8	51.5	49.4	53.6
2 A.	50.5	52.5	54.3	51.3	46.3	54.3	53.8	51.0	51.0	53.5	53.5	53.8
3 A.	50.9	52.6	54.0	52.2	49.1	52.1	54.0	47.5	50.8	51.5	50.5	54.3
4 A.	51.4	53.1	54.3	52.0	46.4	54.8	54.0	51.0	51.1	54.0	54.0	56.5
Means	50.9	52.7	54.1	51.8	47.6	53.3	53.7	49.3	50.9	52.6	51.9	54.9
1 AA.	49.1	51.3	52.8	50.6	48.3	52.0	53.5	47.5	50.7	51.8	50.0	53.9
2 AA.	49.5	51.7	52.4	50.1	46.1	53.5	53.3	50.7	51.3	53.5	54.4	55.7
3 AA.	50.6	51.3	53.1	50.2	47.3	52.1	53.9	47.5	50.4	51.5	51.5	54.5
4 AA.	50.6	51.4	52.1	48.9	45.4	53.9	53.5	50.5	51.0	53.5	54.0	56.4
Means	50.0	51.4	52.6	50.0	46.8	52.9	53.6	49.1	50.9	52.6	52.5	55.1
1 AAS.												
2 AAS.												
3 AAS.												
4 AAS.												
Means												
1 O.	51.7	51.3	52.9	50.5	46.1	53.2	53.5	52.0	52.0	54.0	54.5	56.9
2 O.	51.8	51.6	52.8	50.0	47.3	53.8	52.8	51.5	51.5	54.1	55.3	56.4
3 O.	51.3	51.5	52.6	50.6	46.6	54.1	53.5	51.7	51.8	53.5	53.5	56.8
4 O.	51.4	50.4	52.8	49.5	46.3	54.1	53.1	51.0	51.1	54.3	54.0	56.7
Means	51.6	51.2	52.8	50.2	46.6	53.8	53.2	51.6	51.6	54.0	54.3	56.6
N.												
2 N.	(51.7)	51.3	53.3	52.0	50.0	52.9	53.5	48.0	51.0	52.0	51.5	53.4
		49.7	53.1	50.1	48.4	53.0	54.0	48.5	51.1	51.8	51.3	53.9
M.												
6 O.	(51.0)	51.8	53.1	52.6	47.5	53.4	54.0	51.0	51.0	53.3	51.5	54.1
5 A.	51.0	52.3	53.8	51.5	46.6	54.5	54.0	51.0	51.2	53.0	52.0	55.6
5 (1	52.0	50.3	52.8	52.5	50.0	52.3	53.1	48.5	51.3	52.0	51.8	54.9
2	53.0	50.9	53.6	52.6	50.0	52.3	53.1	47.5	51.0	52.0	52.0	54.1
	52.8	51.6	53.9	52.9	47.1	54.2	54.5	52.5	52.1	54.8	54.8	57.3

(1) Averages of 4 years, 4 years, and 8 years.

(2) Averages of 9 years (1853-'61), last 10 years.

(4) Averages of 9 years (1853-'61).

ANURE, and with different descriptions of Manure. Hoos Field, Rothamsted.

Bushel of Dressed Corn—lbs.

the period indicated, for particulars of which see *Appendix-Table I.*, and side-notes thereto, p. 179.]

HARVESTS.								AVERAGE ANNUAL.			PLOTS.
1861.	1865.	1866.	1867.	1868.	1869.	1870.	1871.	First 10 Years, 1862-'71.	Second 10 Years, 1862-'71.	Total Period, 20 Years, 1862-'71.	
lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
55.7	53.9	51.1	51.8	54.3	52.4	52.9	55.0	51.6	53.1	52.3	1 O.
56.8	53.8	53.2	53.9	55.8	54.3	53.6	56.0	52.0	54.4	53.2	2 O.
56.9	54.5	52.3	52.9	55.7	54.7	54.3	55.4	51.8	54.3	53.0	3 O.
57.3	54.0	52.7	53.6	55.3	54.6	55.6	55.6	52.3	54.6	53.4	4 O.
56.7	54.1	52.3	53.1	55.3	54.0	54.1	55.5	52.0	54.1	53.0	Means
56.4	53.8	50.9	51.3	53.3	52.4	54.6	55.6	51.2	53.0	52.1	1 A.
57.0	52.7	54.4	54.1	54.6	57.0	57.2	55.0	51.8	55.1	53.5	2 A.
56.4	54.7	52.1	51.9	54.8	54.6	55.4	56.1	51.5	54.1	52.8	3 A.
57.6	53.5	54.7	54.3	55.6	57.4	57.1	56.5	52.2	55.7	54.0	4 A.
56.6	53.7	53.0	52.9	54.6	55.4	56.1	55.8	51.6	54.5	53.1	Means
56.5	53.5	50.9	52.4	53.7	53.1	54.5	54.1	50.8	53.2	52.0	1 AA.
57.2	52.3	55.0	54.1	55.6	57.2	56.9	56.9	51.2	55.4	53.3	2 AA.
56.5	54.8	51.4	51.9	55.1	53.7	54.6	54.3	50.8	53.8	52.3	3 AA.
57.6	53.3	55.4	54.6	56.0	57.1	57.1	56.3	51.1	55.8	53.4	4 AA.
56.7	53.5	53.2	53.3	55.1	55.3	55.8	55.2	51.0	54.6	52.8	Means
56.1	54.2	51.8	53.5	54.2	54.8	55.0	54.6	(1) { 53.9 55.1 54.4 54.9	54.6	54.3	1 AAS.
57.2	52.4	55.6	55.1	56.2	57.4	57.4	55.6		56.7	55.9	2 AAS.
57.2	54.8	52.5	53.0	55.5	56.6	56.9	53.8		55.5	55.0	3 AAS.
57.0	53.1	55.3	54.1	56.2	57.8	57.8	55.4		56.8	55.8	4 AAS.
56.9	53.6	53.8	53.9	55.5	56.7	56.5	54.9	54.6	55.9	55.2	Means
57.1	53.8	55.1	54.4	56.2	56.7	57.5	56.3	51.7	55.8	53.8	1 C.
57.0	53.3	55.7	55.0	56.1	57.1	57.8	56.4	51.7	56.0	53.9	2 C.
57.3	53.3	55.3	54.7	56.8	57.1	57.6	56.3	51.7	55.8	53.7	3 C.
57.2	53.5	55.6	54.8	55.4	57.4	58.0	56.4	51.4	55.9	53.6	4 C.
57.1	53.5	55.4	54.7	55.9	57.1	57.7	56.4	51.6	55.9	53.8	Means
56.0	54.1	52.0	52.9	52.8	54.3	55.6	54.6	(2) { 51.6 51.1	53.7	52.7	1 N.
56.5	53.8	52.8	52.7	55.5	54.8	55.8	54.6		54.2	52.7	2 N.
56.3	54.4	52.9	53.9	54.0	54.0	55.3	55.0	(3) { 51.8 52.0	54.2	53.2	M.
57.6	54.5	53.4	54.0	56.4	55.6	55.9	55.1		54.8	53.4	5 O.
57.5	54.1	54.8	55.2	57.5	57.5	57.3	55.5	51.9	55.7	53.8	5 A.
56.0	53.9	51.8	52.0	53.5	52.8	54.0	55.4	51.5	53.5	52.5	1) 6
56.8	53.9	51.8	52.5	53.8	52.9	54.6	54.9	51.6	53.6	52.6	2) 6
57.4	54.4	54.9	54.8	57.1	56.4	57.1	56.6	52.6	56.0	54.3	7

and total 19 years.

(2) Averages of 7 years (1855-'61), last 10 years, and total 17 years.

last 10 years, and total 19 years.

EXPERIMENTS ON THE GROWTH OF BARLEY year after year on the same Land

APPENDIX-TABLE

[N.B. The double vertical lines show that there was a change in the description, or quantity]

PLOTS	HARVESTS.									
	1852.	1853.	1854.	1855.	1856.	1857.	1858.	1859.	1860.	1861.
1 O.	lbs. 164	lbs. 225	lbs. 84	lbs. 144	lbs. 131	lbs. 93	lbs. 86	lbs. 110	lbs. 78	lbs. 88
2 O.	100	101	101	69	58	106	103	159	84	78
3 O.	183	151	64	76	129	61	96	85	78	58
4 O.	136	160	105	94	88	53	108	160	74	58
Means	146	159	89	96	102	78	98	129	78	72
1 A.	218	253	201	138	219	113	98	184	150	170
2 A.	260	244	150	184	121	88	114	274	159	130
3 A.	252	336	197	177	180	91	96	175	115	109
4 A.	273	274	138	142	125	70	117	253	150	116
Means	251	277	172	160	161	91	106	222	143	130
1 AA.	299	303	326	204	310	135	88	215	109	173
2 AA.	315	251	329	181	233	133	134	320	118	190
3 AA.	318	236	334	212	290	108	118	265	122	138
4 AA.	246	301	273	150	176	183	143	285	141	179
Means	294	273	316	187	252	140	121	271	123	170
1 AAS.										
2 AAS.										
3 AAS.										
4 AAS.										
Means										
1 C.	170	268	178	219	173	135	103	225	120	154
2 C.	164	376	238	195	161	169	148	171	156	150
3 C.	190	296	248	183	189	156	105	236	115	204
4 C.	144	277	227	222	205	168	125	350	153	204
Means	167	304	223	205	182	157	120	246	136	178
1 N.	(94)	283	109	128	245	99	119	205	146	225
2 N.		228	286	224	193	151	110	235	179	190
M.				36	94	90	84	85	75	78
5 O.	(173)	68	113	50	96	101	71	110	73	73
5 A.	173	210	170	126	151	68	154	168	193	188
6 {1	120	200	144	116	152	72	84	121	88	73
2	118	161	119	73	125	105	81	127	95	67
7	101	269	86	109	141	134	121	260	147	190

(1) Averages of 4 years, 4 years, and 8 years.

(2) Averages of 9 years (1853-61), &c.

(4) Averages of 9 years &c.

ANURE, and with different descriptions of MANURE. Hoos Field, Rothamsted.

rn per Acre—lbs.

the period indicated, for particulars of which see *Appendix-Table I.*, and side-notes thereto, p. 179.]

HARVESTS.								AVERAGE ANNUAL.			PLOTS.
1864.	1865.	1866.	1867.	1868.	1869.	1870.	1871.	First 10 Years, 1862-'61.	Second 10 Years, 1862-'71.	Total Period, 20 Years, 1862-'71.	
lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
42	47	41	90	21	44	31	48	120	48	84	1 O.
69	38	21	53	29	89	18	33	96	52	74	2 O.
43	38	38	64	27	70	18	35	101	46	74	3 O.
41	28	55	60	25	69	26	48	104	53	78	4 O.
49	38	39	67	25	68	23	41	105	50	78	Means
99	58	94	115	49	139	23	105	174	107	141	1 A.
63	84	64	76	38	113	26	189	172	94	133	2 A.
83	51	106	94	34	95	24	89	173	95	134	3 A.
110	60	63	71	50	21	27	146	165	78	122	4 A.
89	63	82	89	43	92	25	132	171	94	133	Means
110	64	148	110	46	64	33	133	216	111	164	1 AA.
50	113	111	69	46	89	24	168	220	95	158	2 AA.
76	48	103	106	59	111	36	133	214	113	164	3 AA.
46	76	133	119	43	78	30	90	208	87	148	4 AA.
71	75	124	101	48	86	31	131	215	102	159	Means
94	55	88	85	49	121	33	94	81	74	77	1 AAS
53	86	96	66	64	60	23	153	75	75	75	2 AAS.
70	50	141	79	39	136	29	130	85	84	85	3 AAS.
93	70	80	93	46	125	26	175	84	93	89	4 AAS.
77	65	101	81	50	111	28	138	81	82	82	Means
78	83	104	109	43	69	25	78	175	83	129	1 C.
92	44	89	89	64	111	24	88	193	84	138	2 C.
90	66	94	91	39	91	37	141	192	91	142	3 C.
123	69	128	72	42	67	28	124	208	89	149	4 C.
96	66	104	90	47	85	28	108	192	87	139	Means
74	98	124	119	61	150	33	99	173	112	141	1 N.
95	84	104	88	35	98	33	171	199	104	149	2 N.
58	69	44	56	26	61	25	58	(²) 77	64	69	M.
78	35	48	56	20	75	23	41	(²) 84	61	72	5 O.
91	94	53	74	33	63	30	144	160	87	124	5 A.
51	45	72	103	27	71	26	50	117	57	87	1 } ₆
54	47	51	83	21	57	23	41	107	64	85	2 }
117	56	148	111	48	100	26	171	156	105	130	7

and total 19 years.

last 10 years, and total 19 years.

(¹) Averages of 7 years (1855-'61), last 10 years, and total 17 years.

EXPERIMENTS ON THE GROWTH OF BARLEY year after year on the same LAND, with

APPENDIX-TABLE V. *Id.*

[N.B. The double vertical lines show that there was a change in the description, or quantity, of Manure]

PLOTS.	HARVESTS.											
	1852.	1853.	1854.	1855.	1856.	1857.	1858.	1859.	1860.	1861.	1862.	1863.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1 O.	1585	1552	1963	1773	812	1453	1207	775	753	941	899	1376
2 O.	1605	1867	2298	1973	886	1861	1657	1179	884	1410	1253	1614
3 O.	1558	1586	2021	1918	936	1741	1396	872	847	1084	1094	1557
4 O.	1819	2017	2374	2067	1018	2191	1780	1197	1013	1648	1428	1863
Means	1642	1755	2164	1933	913	1811	1510	1006	874	1271	1168	1629
1 A.	2088	2285	2763	2443	1432	2133	1771	919	1501	1745	1821	2406
2 A.	2212	2352	3437	2639	1467	3161	2879	2034	2371	3073	2791	3311
3 A.	2091	2259	2897	2504	1577	2302	1946	977	1540	1799	2049	2748
4 A.	2368	2309	3428	2659	1599	3216	2897	2017	2375	3059	2725	3219
Means	2190	2301	3131	2561	1519	2703	2374	1487	1947	2419	2346	2909
1 AA.	2486	2394	3313	2640	2061	2725	2198	1237	1395	1986	1874	2733
2 AA.	2483	2435	3643	2707	1687	3696	3131	2140	2338	3178	2908	3515
3 AA.	2431	2358	3075	2586	1489	2708	2811	1235	1672	2038	2234	3002
4 AA.	2532	2590	3539	2582	1886	3677	3155	2092	2501	3169	2824	3430
Means	2483	2444	3393	2629	1781	3202	2699	1676	1977	2593	2450	3185
1 AAS.												
2 AAS.												
3 AAS.												
4 AAS.												
Means												
1 C.	2198	2318	3388	2668	1870	3547	2980	2245	1773	3209	2389	3005
2 C.	2057	2243	3444	2857	1916	3521	3174	2284	2051	3227	2619	3213
3 C.	1907	2113	3221	2659	1711	3417	2887	2001	1943	2944	2118	3089
4 C.	2098	2302	3413	2783	1841	3536	3162	2135	2238	3111	2634	3139
Means	2064	2244	3366	2742	1834	3505	3051	2166	2001	3123	2440	3117
1 N.	{(1437)}	2044	2740	2727	1675	2634	2144	1400	1546	2215	2075	2673
2 N.		2071	3113	2696	2225	3226	2480	1525	1703	2345	2184	3016
M.				1730	1016	1379	1476	1055	618	1563	1443	1563
5 O.	(2034)	1493	1748	1759	1009	1764	1441	955	593	1598	1088	1641
5 A.	2034	2306	2959	2596	1700	3061	2754	1857	2188	2808	2635	2944
6 {1	1627	1521	1998	2074	910	1899	1496	954	719	940	1031	1367
{2	1451	1555	1904	1982	923	1738	1422	831	718	1000	1182	1613
7	1844	2136	3127	2765	1656	2915	3118	2362	2319	3169	2936	3473

(¹) Averages of 4 years, 4 years, and 8 years.(²) Averages of 9 years (1853-'61), last 10 years.(³) Averages of 9 years (1853-'61).

MANURE, and with different descriptions of MANURE. Hoos Field, Rothamsted.

ton per Acre—lbs.

the period indicated, for particulars of which see *Appendix-Table I.*, and side-notes thereto, p. 179.]

HARVESTS.								AVERAGE ANNUAL.			PLOTS:.
1864.	1865.	1866.	1867.	1868.	1869.	1870.	1871.	First 10 Years, 1862-'61.	Second 10 Years, 1862-'71.	Total Period, 20 Years, 1852-'71.	
lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
1379	1018	858	978	873	840	751	973	1281	985	1133	1 O.
1790	1252	1216	1386	1060	1079	986	1829	1562	1317	1439	2 O.
1526	1237	1041	962	824	1097	928	1125	1396	1139	1268	3 O.
1949	1349	1323	1180	998	1286	1053	1438	1712	1387	1550	4 O.
1661	1214	1109	1126	939	1075	929	1216	1488	1207	1347	Means
2258	1666	1474	1686	1136	1599	1539	2129	1908	1771	1840	1 A.
3399	2636	2809	2458	2092	2849	2404	2672	2563	2762	2662	2 A.
2563	1872	1541	1808	1406	1994	1733	2231	1989	1995	1992	3 A.
3316	2549	2636	2454	1978	2848	2197	2769	2593	2668	2630	4 A.
2884	2181	2115	2101	1653	2322	1968	2450	2263	2299	2281	Means
2430	1875	1633	1669	1500	1773	1630	2250	2244	1939	2091	1 AA.
3300	2600	2913	2464	2492	2845	2655	2771	2744	2846	2795	2 AA.
2600	1920	1631	1814	1578	1929	1803	2098	2190	2065	2128	3 AA.
3299	2684	2954	2573	2586	2929	2571	2683	2772	2853	2813	4 AA.
2907	2270	2283	2130	2039	2369	2165	2451	2487	2426	2457	Means
2573	1948	2054	1811	1644	2029	1963	2721	(1) { 2097 2796 2437 2912	2089	2093	1 AAS.
3190	2564	2939	2490	2585	2924	2593	2904		2752	2774	2 AAS.
2933	2299	2341	2173	2061	2429	2424	2731		2411	2424	3 AAS.
3465	2751	2888	2543	2669	3118	2755	2886		2857	2884	4 AAS.
3040	2391	2556	2254	2240	2625	2434	2811	2560	2527	2544	Means
2828	2508	2631	2209	2122	2482	2429	2561	2619	2516	2568	1 C.
3039	2503	2741	2594	2044	2867	2437	2445	2677	2650	2664	2 C.
2923	2666	2518	2221	1999	2584	2260	2695	2480	2507	2494	3 C.
3153	2648	2834	2411	2051	3065	2569	2809	2662	2733	2698	4 C.
2986	2581	2681	2359	2054	2750	2424	2628	2610	2602	2606	Means
2360	2101	1910	1866	1410	2064	1966	2451	(2) { 2124 2376	2108	2116	1 N.
2710	2326	2266	2008	1443	2218	2278	2650		2300	2336	2 N.
1519	1145	1048	1161	821	957	915	1275	(2) { 1262	1185	1217	M.
1610	1290	1248	1111	868	1378	835	1143	(2) { 1373	1221	1293	5 O.
3015	2710	2461	2001	2114	2981	2424	2604	2426	2584	2505	5 A.
1461	1180	899	953	846	857	851	1091	1414	1070	1242	1) 6
1454	1084	948	1121	876	873	853	1375	1352	1138	1245	2) 6
3672	2923	3065	2614	2539	2746	2734	3243	2541	2995	2768	7

and total 19 years.

(*) Averages of 7 years (1855-'61), last 10 years, and total 17 years.

and total 10 years, and total 19 years.

EXPERIMENTS ON THE GROWTH OF BARLEY year after year on the same LAND, without

APPENDIX-TABLE VI. *See*

[N.B. The double vertical lines show that there was a change in the description, or quantity, of Manure.

PLOTS.	HARVESTS.											
	1852.	1853.	1854.	1855.	1856.	1857.	1858.	1859.	1860.	1861.	1862.	1863.
1 O.	Cwts. 16½	Cwts. 18	Cwts. 21½	Cwts. 17½	Cwts. 8½	Cwts. 12½	Cwts. 10½	Cwts. 9½	Cwts. 7½	Cwts. 11	Cwts. 9½	Cwts. 11½
2 O.	16½	17½	23½	17½	8½	15½	14½	12½	8½	13½	12½	15½
3 O.	16½	17½	20½	17½	9½	15	12½	9½	8½	11½	10½	12½
4 O.	19½	20½	23½	18	9½	17½	16½	12½	9½	15½	13½	15½
Means	17½	18½	22½	17½	9	15½	13½	10½	8½	12½	11½	13½
1 A.	22½	23½	30½	24½	17½	17½	15½	11½	14½	19½	20½	21½
2 A.	26	25½	40½	29½	21½	26½	28½	24½	25½	29½	32½	34
3 A.	23½	25½	33½	27½	17½	21½	17½	13½	16½	21½	23½	26½
4 A.	27½	26½	40½	31	21½	27½	29½	27½	26½	30½	31½	32
Means	25½	25½	36½	28	19½	23½	22½	19½	20½	25½	26½	28½
1 AA.	26½	26½	37½	32½	24½	23½	19½	14½	13½	22	21½	23½
2 AA.	28½	28½	44½	38½	31½	32½	32½	26½	24½	31½	31½	32½
3 AA.	26½	27½	37½	34	26½	26	22½	16½	18½	24½	24½	27½
4 AA.	28½	31½	49	39½	33	36½	35½	30½	29	33½	33½	34½
Means	27½	28½	42½	36½	28½	29½	27½	21½	21½	27½	27½	30
1 AAS.												
2 AAS.												
3 AAS.												
4 AAS.												
Means												
1 C.	24½	26½	43½	36½	26	33½	30½	26½	17½	27½	26	28½
2 C.	23½	25½	44½	36½	31½	3½	33½	28½	20½	30½	27½	30½
3 C.	21½	25½	41½	35½	26½	30½	30½	25½	20½	30½	23½	28½
4 C.	24½	27½	42½	37½	30½	33½	35	29½	22½	31	28½	30½
Means	23½	26½	42½	36½	28½	32½	32½	27½	20½	30	26½	28½
1 N.		23½	33½	27	19½	24½	20½	18½	16½	27½	24½	28½
2 N.	(15½)	25½	38½	33½	28½	32	23½	21½	18½	29½	24½	28½
M.				15½	10½	10½	12½	10½	7½	15½	14½	19½
5 O.	(25½)	15½	20½	14½	10½	13½	12½	10½	6½	17½	10½	15½
5 A.	25½	24	35½	31	22½	27½	28½	26½	25½	31½	31½	34
6(1	17½	16½	22½	18½	9½	16½	12	11½	7½	9½	10½	13½
2	14½	15½	20½	16½	9½	14½	11½	10	7½	10	11½	14
7	18½	22½	37½	27½	19½	23½	31½	28½	25½	31½	34½	33½

(1) Averages of 4 years, 4 years, and 8 years.

(2) Averages of 9 years (1853-'61), last 10 years

(4) Averages of 9 years (1853-'61)

[ANURE, and with different descriptions of MANURE. Hoos Field, Rothamsted.
and Chaff) per Acre—Cwts.

the period indicated, for particulars of which see *Appendix-Table I.*, and side-notes thereto, p. 179.]

HARVESTS.								AVERAGE ANNUAL.			PLOTS.
1864.	1865.	1866.	1867.	1868.	1869.	1870.	1871.	First 10 Years, 1852-'61.	Second 10 Years, 1862-'71.	Total Period, 20 Years, 1852-'71.	
Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	
12½	8½	9½	10½	11½	11	6½	11	13½	10½	11½	1 O.
15½	9½	12½	12½	9½	10½	8	12½	14½	11½	13½	2 O.
18½	9½	10½	10½	8½	11	8½	11½	13½	10½	12½	3 O.
16½	10	12½	12	10½	12½	9½	14	16½	12½	14½	4 O.
14½	9½	11½	11½	9½	11½	8½	12½	14½	11½	12½	Means
20½	13	15½	17½	12½	18½	12½	23½	19½	17½	18½	1 A.
32½	21½	28½	28½	19½	32	17½	28½	27½	27½	27½	2 A.
19½	16	16½	19½	14½	20½	15	25½	21½	19½	20½	3 A.
34½	22½	27½	25½	20½	34½	18½	32½	28½	28	28½	4 A.
26½	18½	21½	22½	16½	26½	16	27½	24½	23½	23½	Means
23½	16	17½	17½	14½	21½	17½	26½	24	20½	22½	1 AA.
33½	23	28½	30½	21½	34½	23½	32½	31½	29½	30½	2 AA.
26½	17	18½	20½	16½	22½	20½	25½	25½	22½	24	3 AA.
37½	24½	28½	28½	25½	38½	18½	32½	34½	30½	32½	4 AA.
30½	20½	23½	24½	19½	29½	20½	29½	29	25½	27½	Means
26½	22½	20½	18½	16½	23½	17	29½	(¹) 21½	21½	21½	1 AAS.
33½	23½	30½	29½	25½	37½	20½	36½	(¹) 29½	29½	29½	2 AAS.
30½	20½	25	23½	22	30½	20½	31½	(¹) 24½	26½	25½	3 AAS.
40½	25½	29½	28½	26½	42½	20½	38	(¹) 31	32	31½	4 AAS.
32½	22½	26½	24½	22½	33½	19½	33½	26½	27½	27	Means
26½	21½	24½	25½	19½	27	17½	27½	29½	24½	26½	1 C.
31½	21½	24½	25½	19½	33½	17½	27½	30½	26	28½	2 C.
31	22	24½	22½	19½	30½	18½	30½	28½	25½	27½	3 C.
34½	22	27½	24½	21½	35½	20½	32	31½	27½	29½	4 C.
31	21½	25½	24½	19½	31½	18½	29½	30½	25½	28	Means
24½	18½	21½	21½	18½	24	13½	29½	(¹) 23½	22½	22½	1 N.
27½	21½	23½	21½	17½	27½	19½	31½	(¹) 27½	24½	26½	2 N.
13½	9½	12½	12	10½	11½	8½	14½	(¹) 11½	12½	12½	M.
14½	10½	10½	10½	8½	15½	4½	13½	(¹) 13½	11½	12½	5 O.
33½	24½	28	22½	20½	36½	21½	29½	27½	28½	28	5 A.
13½	8½	10½	9½	10½	9½	7½	13	14	10½	12½	1) 6
13½	8½	9½	10½	10½	10½	7½	13½	13	11½	12½	2) 6
37½	25½	31½	27½	24½	28½	19½	37½	26½	29½	28½	7

and total 19 years. (¹) Averages of 7 years (1855-'61), last 10 years, and total 17 years.
last 10 years, and total 19 years.

EXPERIMENTS ON THE GROWTH OF BARLEY year after year on the same LAND, without

APPENDIX-TABLE VII. Total Product

[N.B. The double vertical lines show that there was a change in the description, or quantity, of Manure]

PLOTS.	HARVESTS.											
	1852.	1853.	1854.	1855.	1856.	1857.	1858.	1859.	1860.	1861.	1862.	1863.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1 O.	3445	3562	4405	3745	1797	2878	2424	1800	1598	2166	1987	2545
2 O.	3459	3788	4398	3955	1865	3606	3327	2559	1877	2900	2701	3568
3 O.	3405	3521	4353	3873	1961	3426	2771	1962	1802	2369	2309	3089
4 O.	4008	4312	4969	4082	2075	4111	3590	2567	2093	3366	2941	3586
Means	3579	3794	4656	3914	1924	3505	3028	2222	1842	2700	2484	3199
1 A.	4652	4950	6155	5148	3347	4118	3506	2204	3166	3945	4106	4806
2 A.	5127	5202	8017	5929	3874	6161	6099	4814	5196	6411	6416	7319
3 A.	4730	5079	6672	5579	3574	4702	3951	2487	3355	4212	4658	5691
4 A.	5487	5284	7958	6134	3981	6386	6192	5067	5355	6472	6273	6791
Means	4999	5129	7200	5697	3694	5329	4937	3643	4268	5260	5363	6152
1 AA.	5490	5324	7548	6242	4801	5360	4345	2857	2905	4449	4247	5561
2 AA.	5662	5615	8619	7027	5233	7383	6791	5105	5053	6721	6443	7168
3 AA.	5378	5405	7315	6388	4414	5618	4791	3035	3702	4743	5003	6168
4 AA.	5714	6134	9026	7054	5582	7734	7160	5517	5746	6937	6539	7323
Means	5561	5619	8127	6678	5008	6524	5772	4128	4352	5713	5556	6559
1 AAS.												
2 AAS.												
3 AAS.												
4 AAS.												
Means												
1 C.	4949	5323	8238	6720	4780	7262	6425	5260	3771	6332	5299	6214
2 C.	4713	5110	8388	6904	5447	7266	6964	5509	4356	6625	5669	6593
3 C.	4351	4943	7848	6676	4673	6877	6837	4866	4198	6392	4786	6129
4 C.	4796	5386	8125	6993	5257	7241	7082	5440	4783	6576	5872	6399
Means	4702	5190	8150	6823	5039	7161	6702	5269	4277	6481	5407	6459
1 N.	(3143)	4631	6475	5757	3877	5389	4399	3500	3416	5260	4793	6265
2 N.		4906	7400	6416	5450	6816	5125	3905	3793	5665	4959	6366
M.				3440	2206	2538	2856	2275	1433	3263	3061	3740
5 O.	(4843)	3263	4015	3394	2169	3254	2846	2125	1363	3563	2966	3354
5 A.	4843	4996	6964	6066	4247	6161	5954	4777	5038	6373	6175	6749
6 ⁽¹⁾	3550	3371	4519	4100	1952	3711	2846	2212	1560	2048	2189	3043
6 ⁽²⁾	3030	3336	4221	3857	1981	3375	2693	1948	1581	2117	2480	3221
7	3920	4682	7298	5852	3866	5564	6635	5558	5156	6715	6774	7185

(1) Averages of 4 years, 4 years, and 8 years.

(2) Averages of 9 years (1853-'61), last 10 years.

(4) Averages of 9 years (1853-'61).

with different descriptions of MANURE. Hoos Field, Rothamsted.

and Chaff) per Acre—lbs.

icated, for particulars of which see *Appendix-Table I.*, and side-notes thereto, p. 179.

HARVESTS.						AVERAGE ANNUAL.			PLOTS.
1866.	1867.	1868.	1869.	1870.	1871.	First 10 Years, 1862-'61.	Second 10 Years, 1862-'71.	Total Period, 20 Years, 1862-'71.	
lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
1928	2124	2173	2075	1489	2208	2782	2126	2454	1 O.
2636	2759	2110	2238	1884	2694	3223	2639	2931	2 O.
2191	2098	1789	2333	1882	2380	2944	2338	2641	3 O.
2759	2526	2126	2729	2101	3002	3517	2807	3162	4 O.
2378	2377	2049	2344	1839	2571	3116	2478	2797	Means
3200	3611	2507	3640	2945	4712	4119	3719	3919	1 A.
5955	5658	4255	6430	4412	5820	5683	5837	5760	2 A.
3412	3977	3074	4319	3406	5080	4434	4200	4317	3 A.
5704	5304	4311	6701	4287	6404	5827	5808	5817	4 A.
4568	4637	3537	5272	3762	5504	5016	4891	4953	Means
3628	3589	3130	4181	3628	5250	4932	4192	4562	1 AA.
6068	5917	4937	6750	5315	6371	6321	6114	6217	2 AA.
3661	4144	3401	4477	4141	4933	5079	4536	4808	3 AA.
6117	5753	5454	7194	4621	6333	6660	6226	6443	4 AA.
4869	4851	4231	5651	4426	5722	5748	5267	5508	Means
4357	3884	3537	4689	3868	6051	(¹)4549	4536	4543	1 AAS.
6327	5790	5410	7082	4851	6954	(¹)6059	6074	6067	2 AAS.
5144	4793	4524	5864	4724	6221	(¹)5209	5333	5271	3 AAS.
6198	5708	5644	7881	5073	7146	(¹)6385	6436	6411	4 AAS.
5507	5044	4779	6379	4629	6594	5551	5595	5573	Means
5337	5064	4267	5512	4358	5637	5906	5236	5571	1 C.
5487	5460	4238	6571	4437	5570	6128	5559	5844	2 C.
5242	4711	4213	5993	4324	6153	5716	5338	5527	3 C.
5929	5121	4414	7001	4857	6394	6168	5837	6002	4 C.
5499	5089	4283	6269	4494	5939	5980	5493	5736	Means
4275	4234	3530	4759	3456	5726	(²)4745	4628	4683	1 N.
4941	4438	3366	5313	4413	6175	(²)5497	5042	5258	2 N.
2436	2499	2044	2265	1903	2920	(³)2573	2614	2597	M.
2443	2271	1826	3111	1323	2618	(⁴)2888	2498	2682	5 O.
5591	4511	4419	6979	4817	5927	5542	5747	5644	5 A.
2078	2026	2019	1957	1720	2554	2987	2273	2630	1 } ₆
2017	2344	2097	2031	1740	2896	2814	2391	2603	2 }
6594	5652	5281	5959	4950	7401	5525	6342	5933	7

years. (²) Averages of 7 years (1855-'61), last 10 years, and total 17 years.
and total 19 years.

EXPERIMENTS ON THE GROWTH OF BARLEY year after year on the same LAND, without

APPENDIX-TABLE VIII. Increase by Manure (over the

[N.B. The double vertical lines show that there was a change in the description, or quantity, of Manure]

PLOTS	HARVESTS.											
	1852.	1853.	1854.	1855.	1856.	1857.	1858.	1859.	1860.	1861.	1862.	1863.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1 O.												
2 O.	- 1	330	317	49	25	185	305	314	148	470	288	412
3 O.	- 48	49	40	- 6	75	65	44	7	111	144	129	155
4 O.	213	480	393	143	157	515	428	332	277	708	463	466
Means	55	286	250	62	86	255	259	218	179	441	293	344
1 A.	482	748	782	519	571	457	419	54	765	805	856	1004
2 A.	606	815	1456	715	606	1485	1527	1169	1635	2133	1826	2109
3 A.	485	722	916	580	716	626	594	112	804	859	1084	1346
4 A.	762	772	1447	735	738	1540	1545	1152	1639	2119	1760	1806
Means	584	764	1150	637	658	1027	1021	622	1211	1479	1382	1567
1 AA.	880	857	1332	716	1200	1049	846	372	659	1046	909	1351
2 AA.	877	898	1662	783	826	2020	1779	1275	1602	2238	1943	2113
3 AA.	825	821	1094	662	628	1032	959	370	936	1098	1269	1640
4 AA.	926	1053	1558	658	1025	2001	1803	1227	1765	2229	1859	2027
Means	877	907	1412	705	920	1526	1347	811	1241	1653	1495	1783
1 AAS.												
2 AAS.												
3 AAS.												
4 AAS.												
Means												
1 C.	587	781	1407	744	1009	1871	1628	1380	1037	2269	1424	1603
2 C.	451	706	1463	933	1055	1845	1822	1419	1315	2287	1654	1811
3 C.	301	576	1240	735	850	1741	1535	1136	1207	2004	1153	1667
4 C.	492	765	1432	859	980	1860	1810	1270	1502	2171	1669	1757
Means	458	707	1386	818	974	1829	1699	1301	1265	2183	1475	1715
1 N.	- (169)	507	759	803	814	958	792	535	810	1275	1110	1473
2 N.		534	1132	772	1364	1550	1128	660	967	1405	1219	1614
M.				- 194	155	- 297	124	190	- 118	623	478	160
5 O.	(428)	- 44	- 233	- 165	148	88	89	90	- 143	658	123	239
5 A.	428	769	978	672	839	1385	1402	992	1452	1868	1670	1542
6 ¹ / ₂	- 155	18	- 77	58	62	62	70	- 34	- 18	60	217	211
7	238	599	1146	841	795	1239	1766	1497	1583	2229	1971	2071

(1) Averages of 4 years, 4 years, and 8 years.

(2) Averages of 9 years (1853-'61), last 10 years.

(3) Averages of 9 years (1853-'61).

with different descriptions of MANURE. Hoos Field, Rothamsted.

. O. and 6-1), of Total Corn, per Acre—lbs.

icated, for particulars of which see *Appendix-Table I.*, and side-notes thereto, p. 179.]

HARVESTS.						AVERAGE ANNUAL.			PLOTS.
1866.	1867.	1868.	1869.	1870.	1871.	First 10 Years, 1852-'61.	Second 10 Years, 1862-'71.	Total Period, 20 Years, 1852-'71.	
lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
337	420	200	230	185	297	214	289	252	1 O.
162	- 4	- 36	248	127	93	48	112	80	2 O.
444	214	138	437	252	406	365	360	363	3 O.
									4 O.
314	210	101	305	188	265	209	254	232	Means
595	720	276	750	738	1097	560	744	652	1 A.
1930	1492	1232	2000	1603	1640	1215	1735	1475	2 A.
662	842	546	1145	932	1199	641	967	804	3 A.
1757	1488	1118	1999	1396	1737	1245	1641	1443	4 A.
1236	1136	793	1474	1167	1418	915	1272	1094	Means
754	703	640	924	829	1218	896	911	904	1 AA.
2034	1498	1632	1996	1854	1739	1396	1819	1608	2 AA.
752	848	718	1080	1001	1066	843	1038	941	3 AA.
2075	1607	1726	2080	1770	1651	1425	1826	1625	4 AA.
1404	1164	1179	1520	1364	1419	1140	1399	1270	Means
1175	845	784	1180	1162	1689	(¹) { 1006	1204	1105	1 AAS.
2060	1524	1725	2075	1792	1872	(¹) { 1705	1866	1786	2 AAS.
1462	1207	1201	1580	1623	1699	(¹) { 1346	1526	1436	3 AAS.
2009	1577	1809	2269	1954	1854	(¹) { 1821	1972	1896	4 AAS.
1677	1288	1380	1776	1633	1779	1470	1642	1556	Means
1752	1243	1262	1633	1628	1529	1271	1489	1380	1 C.
1862	1628	1184	2018	1636	1413	1330	1623	1477	2 C.
1639	1255	1139	1735	1459	1663	1133	1480	1307	3 C.
1955	1445	1191	2216	1768	1777	1314	1706	1510	4 C.
1802	1393	1194	1901	1623	1596	1262	1575	1419	Means
1031	900	550	1215	1165	1419	(¹) { 806	1081	950	1 N.
1387	1042	583	1369	1477	1618	(¹) { 1057	1273	1170	2 N.
169	195	- 39	108	114	243	(¹) { 69	157	121	M.
369	145	8	529	34	111	(¹) { .54	194	128	5 O.
1582	1035	1254	2082	1623	1572	1079	1557	1318	5 A.
69	155	16	24	52	343	5	111	58	1) ⁶
2186	1648	1679	1897	1933	2211	1193	1967	1580	7

ans. (¹) Averages of 7 years (1855-'61), last 10 years, and total 17 years.
and total 19 years.

EXPERIMENTS ON THE GROWTH OF BARLEY year after year on the same soil

APPENDIX-TABLE IX. Increase by Manure

[N.B. The double vertical lines show that there was a change in the description, &c.]

PLOTS.	HARVESTS.									
	1852.	1853.	1854.	1855.	1856.	1857.	1858.	1859.	1860.	ME.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1 O.										
2 O.	- 38	- 14	118	- 17	- 35	126	386	238	150	23
3 O.	- 45	5	- 150	- 44	11	66	91	- 52	113	112
4 O.	297	365	113	16	43	301	526	228	237	551
Means	71	119	27	- 15	6	164	334	138	166	331
1 A.	672	735	910	706	901	366	451	143	822	1462
2 A.	1023	920	2098	1291	1393	1381	1936	1638	1982	2177
3 A.	747	890	1293	1076	983	781	721	368	973	1244
4 A.	1227	1045	2048	1476	1368	1501	2011	1908	2137	2246
Means	917	898	1587	1137	1161	1007	1280	1014	1478	1671
1 AA.	1112	1000	1753	1603	1726	1016	863	478	667	1294
2 AA.	1287	1250	2494	2321	2532	2068	2376	1823	1872	2373
3 AA.	1055	1117	1758	1803	1911	1291	1196	658	1187	1538
4 AA.	1290	1614	3065	2473	2682	2438	2721	2283	2442	2661
Means.	1186	1245	2253	2050	2213	1703	1789	1311	1532	1951
1 AAS.										
2 AAS.										
3 AAS.										
4 AAS.										
Means										
1 C.	864	1075	2368	2053	1896	2096	2161	1873	1155	1954
2 C.	764	937	2462	2048	2517	2126	2506	2083	1462	2231
3 C.	552	900	2145	2018	1948	1841	2166	1723	1419	2281
4 C.	806	1154	2230	2211	2402	2086	2636	2163	1702	2236
Means	747	1017	2301	2083	2191	2037	2367	1961	1433	2192
1 N.	(- 186)	657	1253	1031	1188	1136	971	958	1027	1678
2 N.		905	1805	1721	2211	1971	1361	1238	1247	2153
M.				- 289	176	- 460	96	78	- 28	533
5 O.	(917)	- 160	- 217	- 364	146	- 129	121	28	- 73	790
5 A.	917	760	1523	1471	1533	1481	1916	1778	2007	2398
6 ⁽¹⁾ ₍₂₎	- 313	- 149	- 165	- 124	44	18	- 13	- 25	20	- 50
7	184	616	1689	1088	1196	1030	2233	2054	1994	2379

(1) Averages of 4 years, 4 years, and 8 years.

(2) Averages of 9 years (1855-63) and

(3) Averages of 2 years

with different descriptions of MANURE. Hoos Field, Rothamsted.

d 6-1), of Straw (and Chaff) per Acre—lbs.

icated, for particulars of which see *Appendix-Table I.*, and side-notes thereto, p. 179.]

HARVESTS.						AVERAGE ANNUAL.			PLOTS.
1866.	1867.	1868.	1869.	1870.	1871.	First 10 Years, 1852-'61.	Second 10 Years, 1862-'71.	Total Period, 20 Years, 1852-'71.	
lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
295	263	- 186	— 9	94	16	124	150	137	1 O.
25	26	- 271	68	150	- 94	11	26	19	2 O.
311	236	- 108	275	244	215	268	248	258	3 O.
									4 O.
210	175	- 188	111	163	46	134	141	138	Means
601	815	135	873	602	1234	674	775	724	1 A.
2021	2090	927	2413	1204	1799	1583	1902	1742	2 A.
746	1059	432	1157	869	1500	908	1083	970	3 A.
1943	1740	1097	2685	1286	2286	1697	1967	1832	4 A.
1328	1426	648	1782	990	1705	1215	1419	1317	Means
870	810	394	1240	1194	1651	1151	1081	1116	1 AA.
2030	2343	1209	2737	1856	2251	2040	2095	2067	2 AA.
905	1221	587	1380	1534	1486	1351	1299	1325	3 AA.
2038	2070	1632	3097	1246	2301	2351	2200	2276	4 AA.
1461	1611	956	2114	1458	1922	1723	1669	1696	Means
1178	963	657	1492	1101	1981	(1288	1308	1298)	1 AAS.
2263	2190	1589	2990	1454	2701	(2099	2184	2141)	2 AAS.
1678	1510	1227	2267	1496	2141	(1608	1783	1696)	3 AAS.
2185	2055	1739	3595	1514	2911	(2309	2440	2275)	4 AAS.
1826	1680	1303	2586	1391	2434	1826	1929	1877	Means
1581	1745	909	1862	1125	1727	1750	1546	1648	1 C.
1621	1756	958	2536	1196	1776	1914	1736	1825	2 C.
1599	1380	978	2241	1260	2109	1699	1658	1678	3 C.
1970	1600	1127	2768	1484	2236	1969	1930	1950	4 C.
1693	1620	993	2352	1266	1962	1833	1718	1775	Means
1240	1258	884	1527	686	1926	(1122	1347	1241)	1 N.
1550	1320	687	1927	1331	2176	(1624	1569	1595)	2 N.
263	228	13	140	184	296	(*) (15	257	157)(*)	M.
70	50	- 278	565	- 316	126	(*) (17	104	62)(*)	5 O.
2005	1400	1069	2880	1589	1974	1578	1991	1784	5 A.
- 56	113	- 15	- 10	83	172	- 76	80	2	1) 6
2404	1928	1506	2045	1412	2809	1447	2174	1811	7

ms. (*) Averages of 7 years (1855-'61), last 10 years, and total 17 years.
 and total 19 years,

EXPERIMENTS on the GROWTH of BARLEY year after year on the same LAND, without

APPENDIX-TABLE X. Increase by Manure (over the Mean of Plots 1 & 2)

[N.B. The double vertical lines show that there was a change in the description, or quantity, of Manure]

PLOTS.	HARVESTS.											
	1852.	1853.	1854.	1855.	1856.	1857.	1858.	1859.	1860.	1861.	1862.	1863.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1 O.	— 39	316	435	32	— 10	311	691	552	298	793	613	775
2 O.	— 93	54	— 110	— 50	86	131	135	— 45	223	262	221	256
3 O.	510	845	506	159	200	816	954	580	514	1259	853	802
4 O.												
Means	126	405	277	47	92	419	593	356	345	771	562	611
1 A.	1154	1483	1692	1225	1472	823	870	197	1587	1838	2018	2012
2 A.	1629	1735	3554	2006	1999	2866	3463	2807	3617	4304	4328	4525
3 A.	1232	1612	2209	1656	1699	1407	1315	480	1776	2105	2570	2897
4 A.	1989	1817	3495	2211	2106	3041	3556	3060	3776	4365	4185	3997
Means	1501	1662	2738	1775	1819	2034	2301	1636	2689	3153	3275	3353
1 AA.	1992	1857	3085	2319	2926	2065	1709	850	1326	2342	2159	2767
2 AA.	2164	2148	4156	3104	3358	4088	4155	3098	3474	4614	4355	4334
3 AA.	1880	1938	2852	2465	2539	2323	2155	1028	2123	2636	2915	3374
4 AA.	2216	2667	4563	3131	3707	4439	4524	3510	4167	4830	4441	4525
Means	2063	2153	3664	2755	3133	3229	3136	2122	2773	3606	3468	3756
1 AAS.												
2 AAS.												
3 AAS.												
4 AAS.												
Means												
1 C.	1451	1856	3775	2797	2905	3967	3789	3253	2192	4225	3211	3420
2 C.	1215	1643	3925	2981	3572	3971	4328	3502	2777	4518	3581	3799
3 C.	853	1476	3385	2753	2798	3582	3701	2859	2619	4285	2698	3635
4 C.	1298	1919	3662	3070	3382	3946	4446	3433	3204	4469	3784	3805
Means	1204	1724	3687	2900	3164	3867	4066	3262	2698	4374	3319	3665
1 N.		1164	2012	1834	2002	2094	1763	1493	1837	3153	2705	3471
2 N.	(- 355)	1439	2937	2493	3575	3521	2459	1898	2214	3558	2871	3572
M.				— 483	331	— 757	220	268	— 146	1156	973	946
5 O.	(1345)	— 204	— 450	— 529	294	— 41	210	118	— 216	1456	178	560
5 A.	1345	1529	2501	2143	2372	2866	3318	2770	3459	4266	4087	3955
6 ⁽¹⁾												
2	— 468	— 131	— 242	— 66	106	80	57	— 59	2	10	392	427
7	422	1215	2835	1929	1991	2269	3999	3551	3577	4608	4686	4391

(1) Averages of 4 years, 4 years, and 8 years.

(2) Averages of 9 years (1853-'61), last 10 years

(3) Averages of 9 years (1853-'61)

† for Twenty Years in succession on the same Land.

197

‡ with different descriptions of MANURE. Hoos Field, Rothamsted.

§ produce (Corn, Straw, and Chaff) per Acre—lbs.

|| indicated, for particulars of which see *Appendix-Table I.*, and side-notes thereto, p. 179.]

HARVESTS.						AVERAGE ANNUAL.			PLOTS.
1866.	1867.	1868.	1869.	1870.	1871.	First 10 Years, 1852-'61.	Second 10 Years, 1862-'71.	Total Period, 20 Years, 1852-'71.	
lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
632	683	14	221	279	313	338	439	389	1 O.
187	22	- 307	316	277	- 1	59	138	99	2 O.
755	450	30	712	496	621	632	607	621	3 O.
									4 O.
525	385	- 88	416	351	311	343	395	370	Means
1196	1535	411	1623	1340	2331	1234	1519	1376	1 A.
3951	3582	2159	4413	2807	3439	2798	3637	3217	2 A.
1408	1901	978	2302	1801	2699	1549	2000	1774	3 A.
3700	3228	2215	4684	2682	4023	2942	3608	3275	4 A.
2564	2562	1441	3256	2158	3123	2130	2691	2411	Means
1624	1513	1034	2164	2023	2869	2047	1992	2020	1 AA.
4064	3841	2841	4733	3710	3990	3436	3914	3675	2 AA.
1657	2069	1305	2460	2535	2552	2194	2336	2265	3 AA.
4113	3677	3358	5177	3016	3952	3776	4026	3901	4 AA.
2865	2775	2135	3634	2821	3341	2863	3067	2965	Means
2553	1808	1441	2672	2263	3670	2294	2512	2403	1 AAS.
4323	3714	3314	5065	3246	4573	(1) 3804	4050	3927	2 AAS.
3140	2717	2428	3847	3119	3840	(1) 2954	3309	3132	3 AAS.
4194	3632	3548	5864	3468	4765	(1) 4130	4412	4271	4 AAS.
3503	2968	2683	4362	3024	4212	3296	3571	3433	Means
3333	2988	2171	3495	2753	3256	3021	3035	3028	1 C.
3483	3384	2142	4554	2832	3189	3244	3359	3302	2 C.
3238	2635	2117	3976	2719	3772	2832	3138	2985	3 C.
3925	3045	2318	4984	3252	4013	3283	3636	3460	4 C.
3495	3013	2187	4252	2889	3558	3095	3293	3194	Means
2271	2158	1434	2742	1851	3345	(*) 1928	2428	2191	1 N.
2937	2362	1270	3296	2508	3794	(*) 2681	2842	2765	2 N.
432	423	- 52	248	298	539	(*) (94	414	278	M.
439	195	- 270	1094	- 282	237	(*) (71	293	190	5 O.
3587	2435	2323	4962	3212	3546	2657	3548	3102	5 A.
13	268	1	14	135	515	- 71	191	60	1)6
4590	3576	3185	3942	3345	5020	2640	4141	3391	7

rs. (2) Averages of 7 years (1855-'61), last 10 years, and total 17 years.
d total 19 years.

EXPERIMENTS ON THE GROWTH OF BARLEY year after year on the same LAND, with

APPENDIX-TABLE XL. O

[N.B. The double vertical lines show that there was a change in the description, or quantity, of Manure]

PLOTS.	HARVESTS.											
	1852.	1853.	1854.	1855.	1856.	1857.	1858.	1859.	1860.	1861.	1862.	1863.
1 O.	11.5	17.0	4.5	8.9	19.3	6.9	7.7	16.5	11.6	10.3	7.6	4.0
2 O.	6.6	5.7	4.6	3.6	7.0	6.1	6.6	15.6	10.6	5.8	10.0	3.8
3 O.	13.3	10.5	3.3	4.1	15.9	3.6	7.4	10.8	10.2	8.8	7.2	3.6
4 O.	8.1	8.6	4.6	4.8	9.5	2.5	6.4	15.4	7.9	3.6	8.9	3.1
Means	9.9	10.5	4.3	5.3	12.9	4.8	7.0	14.6	10.1	7.1	8.4	3.3
1 A.	11.6	12.5	7.9	6.0	18.1	5.6	5.9	25.0	11.1	10.8	17.3	5.1
2 A.	13.3	11.1	4.6	7.5	9.0	2.9	4.1	15.6	7.2	4.4	7.4	2.9
3 A.	13.7	17.5	7.3	7.6	12.9	4.1	5.2	21.8	8.1	6.4	15.1	4.1
4 A.	13.0	13.5	4.2	5.6	8.5	2.2	4.2	14.3	6.7	3.7	5.8	2.6
Means	12.9	13.7	6.0	6.7	12.1	3.7	4.8	19.2	8.3	6.3	11.4	3.7
1 AA.	13.7	14.5	10.9	8.4	17.7	5.2	4.2	21.0	8.5	9.5	18.8	4.2
2 AA.	14.5	11.5	9.9	7.2	16.0	3.7	4.5	17.6	5.3	6.4	4.8	4.2
3 AA.	15.0	11.1	12.2	8.9	24.2	4.2	5.4	27.3	7.9	7.2	19.5	3.2
4 AA.	10.8	13.2	8.3	6.2	10.3	5.2	4.7	15.8	6.0	6.0	7.3	2.0
Means	13.5	12.6	10.3	7.7	17.1	4.6	4.7	20.4	6.9	7.3	12.6	3.4
1 AAS.												
2 AAS.												
3 AAS.												
4 AAS.												
Means												
1 C.	8.4	13.0	5.5	8.9	10.2	4.0	3.6	11.1	7.3	5.0	6.9	2.9
2 C.	8.7	20.2	7.4	7.3	9.2	5.1	4.9	8.1	8.3	4.9	5.1	3.5
3 C.	11.1	16.3	8.3	7.4	12.4	4.8	3.8	13.4	6.3	7.4	9.9	2.3
4 C.	7.4	13.7	7.1	8.7	12.5	5.0	4.1	19.6	7.3	7.0	7.1	2.1
Means	8.9	15.8	7.1	8.1	11.1	4.7	4.1	13.1	7.3	6.1	7.2	2.7
1 N.	(7.0)	16.0	4.1	4.9	17.1	3.9	5.9	17.2	10.5	11.3	13.4	4.4
2 N.		12.3	10.1	9.1	9.5	4.9	4.6	18.2	11.7	8.8	11.0	3.9
M.				2.1	10.2	7.0	6.0	8.8	13.8	5.2	15.9	3.1
5 O.	(9.3)	4.8	6.9	2.9	10.6	6.1	5.2	13.0	13.9	4.8	21.5	2.6
5 A.	9.3	10.0	6.1	5.1	9.8	2.3	5.9	9.9	9.7	7.2	8.7	2.8
6(1	7.9	15.1	7.8	5.9	20.1	3.9	6.0	14.5	13.9	8.4	7.8	3.5
2	8.8	11.6	6.7	3.8	15.7	6.4	6.1	18.0	15.2	7.1	19.6	4.2
7	5.8	14.4	2.8	4.1	9.3	4.8	4.0	12.4	6.8	6.4	7.6	1.9

(1) Averages of 4 years, 4 years, and 8 years.

(2) Averages of 9 years (1853-'61), last 10 years

(3) Averages of 9 years (1853-'61)

with different descriptions of MANURE. Hoos Field, Rothamsted.
essed Corn.

licated, for particulars of which see *Appendix-Table I.*, and side-notes thereto, p. 179.]

HARVESTS.						AVERAGE ANNUAL.			PLOTS.
1866.	1867.	1868.	1869.	1870.	1871.	First 10 Years, 1852-'61.	Second 10 Years, 1862-'71.	Total Period, 20 Years, 1852-'71.	
5.1	10.1	2.4	5.5	4.3	5.2	11.4	5.2	8.3	1 O.
1.7	3.9	2.8	9.0	1.9	2.6	7.2	4.2	5.8	2 O.
3.8	7.1	3.4	6.8	2.0	3.2	8.8	4.3	6.6	3 O.
4.3	5.4	2.6	5.7	2.5	3.4	7.1	4.0	5.6	4 O.
3.7	6.6	2.8	6.8	2.7	3.6	8.6	4.4	6.5	Means
6.8	7.3	4.5	9.6	1.5	5.2	11.5	6.6	9.0	1 A.
2.3	3.2	1.8	4.1	1.1	7.6	8.0	3.6	5.8	2 A.
7.4	5.5	2.5	5.0	1.4	4.1	10.5	5.1	7.8	3 A.
2.5	3.0	2.6	0.8	1.2	5.6	7.6	3.0	5.3	4 A.
4.8	4.8	2.9	4.9	1.3	5.6	9.4	4.6	7.0	Means
9.9	7.1	3.2	3.7	2.0	6.3	11.4	6.3	8.9	1 AA.
4.0	2.9	1.9	3.2	0.9	6.4	9.7	3.4	6.5	2 AA.
6.7	6.2	3.9	6.1	2.1	6.7	12.3	6.0	9.2	3 AA.
4.7	4.8	1.7	2.7	1.2	3.5	8.6	3.2	6.0	4 AA.
6.3	5.3	2.7	4.0	1.5	5.7	10.5	4.7	7.6	Means
4.5	4.9	3.1	6.4	1.7	3.6	(1) { 4.0 2.8 3.7 3.0	3.7	3.9	1 AAS.
3.4	2.7	2.5	2.1	0.9	5.5		2.8	2.8	2 AAS.
6.4	3.8	1.9	5.9	1.2	5.0		3.5	3.6	3 AAS.
2.9	3.8	1.8	4.2	1.0	6.5		3.4	3.2	4 AAS.
4.3	3.8	2.3	4.7	1.2	5.1	3.4	3.3	3.4	Means
4.1	5.2	2.1	2.9	1.0	3.2	7.7	3.5	5.6	1 C.
3.4	3.6	3.2	4.0	1.0	3.7	8.4	3.2	5.8	2 C.
3.9	4.3	2.0	3.7	1.7	5.5	9.1	3.9	6.5	3 C.
4.7	3.1	2.1	2.2	1.1	4.6	9.2	3.4	6.3	4 C.
4.0	4.0	2.3	3.2	1.2	4.3	8.6	3.5	6.1	Means
6.9	6.8	4.5	7.8	1.7	4.2	(2) { 10.1 9.9	5.7	7.8	1 N.
4.8	4.6	2.5	4.6	1.5	6.9		4.7	7.1	2 N.
4.4	5.1	3.3	6.8	2.8	4.7	(2) { 7.6	5.6	6.4	M.
4.0	5.3	2.4	5.8	2.8	3.8	(2) { 7.6	5.6	6.5	5 O.
2.2	3.8	1.6	2.2	1.3	5.8	7.5	3.5	5.5	5 A.
8.7	12.1	3.3	9.0	3.2	4.8	10.4	6.0	8.2	1) 6
5.7	8.0	2.4	7.0	2.8	3.0	9.9	6.1	8.0	2) 6
5.1	4.5	1.9	3.8	1.0	5.6	7.1	3.7	5.4	7

vars. (2) Averages of 7 years (1855-'61), last 10 years, and total 17 years.
and total 19 years.

EXPERIMENTS ON THE GROWTH OF BARLEY year after year on the same land

APPENDIX-TABLE

N.B. The double vertical lines show that there was a change in the description, or quality of the soil.

PLOTS.	HARVESTS.									
	1852.	1853.	1854.	1855.	1856.	1857.	1858.	1859.	1860.	1861.
1 O.	85	77	80	90	82	102	99	76	89	77
2 O.	87	97	88	99	90	107	99	85	89	95
3 O.	84	82	87	98	91	103	102	80	89	84
4 O.	83	88	92	103	96	114	98	87	94	98
Means	85	86	87	97	90	106	99	82	90	88
1 A.	81	86	81	90	75	107	102	72	90	79
2 A.	76	83	75	80	61	105	89	73	84	92
3 A.	79	80	77	81	79	96	97	65	85	75
4 A.	76	78	76	77	67	103	88	66	80	91
Means	78	82	77	82	70	103	94	69	85	84
1 AA.	83	82	78	73	75	103	102	76	92	81
2 AA.	78	77	73	63	48	100	86	72	86	90
3 AA.	82	77	73	68	51	93	93	69	82	75
4 AA.	80	73	65	58	51	91	79	61	77	84
Means	81	77	72	65	56	97	90	70	84	83
1 AAS.										
2 AAS.										
3 AAS.										
4 AAS.										
Means										
1 C.	80	77	70	66	64	95	87	74	89	103
2 C.	77	78	70	71	54	94	84	71	89	95
3 C.	78	75	70	66	58	99	84	70	86	85
4 C.	78	75	72	66	54	95	81	65	88	90
Means	78	76	70	67	58	96	84	70	88	93
1 N.	(84)	79	73	90	76	96	95	67	83	73
2 N.		73	73	72	69	90	94	64	81	71
M.				101	85	119	107	86	76	92
5 O.	(72)	84	77	108	87	118	103	82	77	81
5 A.	72	86	74	75	67	99	86	64	77	79
6 {1	85	82	79	102	87	105	111	76	85	85
2	92	87	82	106	87	106	112	74	83	90
7	89	84	75	90	75	110	89	74	82	89

(1) Averages of 4 years, 4 years, and 8 years.

(2) Averages of 9 years (1853-61) is

(3) Averages of 9 years

MANURE, and with different descriptions of MANURE. Hoos Field, Rothamsted.

Corn to 100 Straw (and Chaff).

at the period indicated, for particulars of which see *Appendix-Table I.*, and side-notes thereto, p. 179.]

HARVESTS.								AVERAGE ANNUAL.			PLOTS.
1864.	1865.	1866.	1867.	1868.	1869.	1870.	1871.	First 10 Years, 1852-'61.	Second 10 Years, 1862-'71.	Total Period, 20 Years, 1852-'71.	
96	112	80	85	67	68	102	79	86	87	87	1 O.
103	123	86	101	101	93	110	97	94	100	97	2 O.
102	114	91	85	85	89	97	90	90	95	92	3 O.
104	121	92	88	89	89	101	92	95	98	96	4 O.
101	117	87	90	85	85	102	89	91	95	93	Means
99	114	85	88	83	78	109	82	86	92	89	1 A.
93	109	89	77	97	80	120	85	82	92	87	2 A.
119	105	82	83	84	86	104	78	81	91	86	3 A.
85	101	86	86	85	74	105	76	80	86	83	4 A.
99	107	85	83	87	79	109	80	82	90	86	Means
93	105	82	87	92	74	82	75	85	87	86	1 AA.
89	101	92	71	102	73	100	77	77	88	83	2 AA.
86	101	80	78	87	76	77	74	76	84	80	3 AA.
79	96	93	81	90	69	125	73	72	87	80	4 AA.
87	101	87	79	93	73	96	75	78	87	82	Means
88	78	89	87	87	76	103	82	(1) { 86 86 89 85	87	86	1 AAS.
85	98	87	75	92	70	115	72		87	87	2 AAS.
87	101	84	83	84	71	105	78		85	87	3 AAS.
76	96	87	80	90	65	119	68		86	85	4 AAS.
84	93	87	82	88	71	111	75	86	86	86	Means
97	104	97	77	99	82	126	83	81	94	87	1 C.
85	102	100	91	93	77	122	78	78	93	86	2 C.
84	108	92	89	90	76	110	78	77	90	84	3 C.
81	107	92	89	87	78	112	78	76	90	83	4 C.
87	105	95	87	92	78	117	79	78	92	85	Means
87	101	81	79	67	77	132	75	(1) { 81 76	86	84	1 N.
87	93	85	83	75	72	107	75		85	81	2 N.
97	109	76	87	67	73	93	78	(1) (95	84	89)	M.
97	108	104	96	91	80	171	77	(1) (91	101	96)	5 O.
79	97	79	80	92	72	101	78	78	83	80	5 A.
96	121	76	89	72	78	98	75	90	89	90	1) 6
94	109	89	92	72	75	96	90	92	91	91	2) 6
88	103	87	86	93	85	123	78	86	91	89	7

and total 19 years. (1) Averages of 7 years (1855-'61), last 10 years, and total 17 years.
last 10 years, and total 19 years.

LONDON:
PRINTED BY WILLIAM CLOWES AND SONS, STAMFORD STREET
AND CHARING CROSS.

UNEXHAUSTED
TILLAGES AND MANURES,
WITH REFERENCE TO THE
LANDLORD AND TENANT (IRELAND) ACT,
1870.



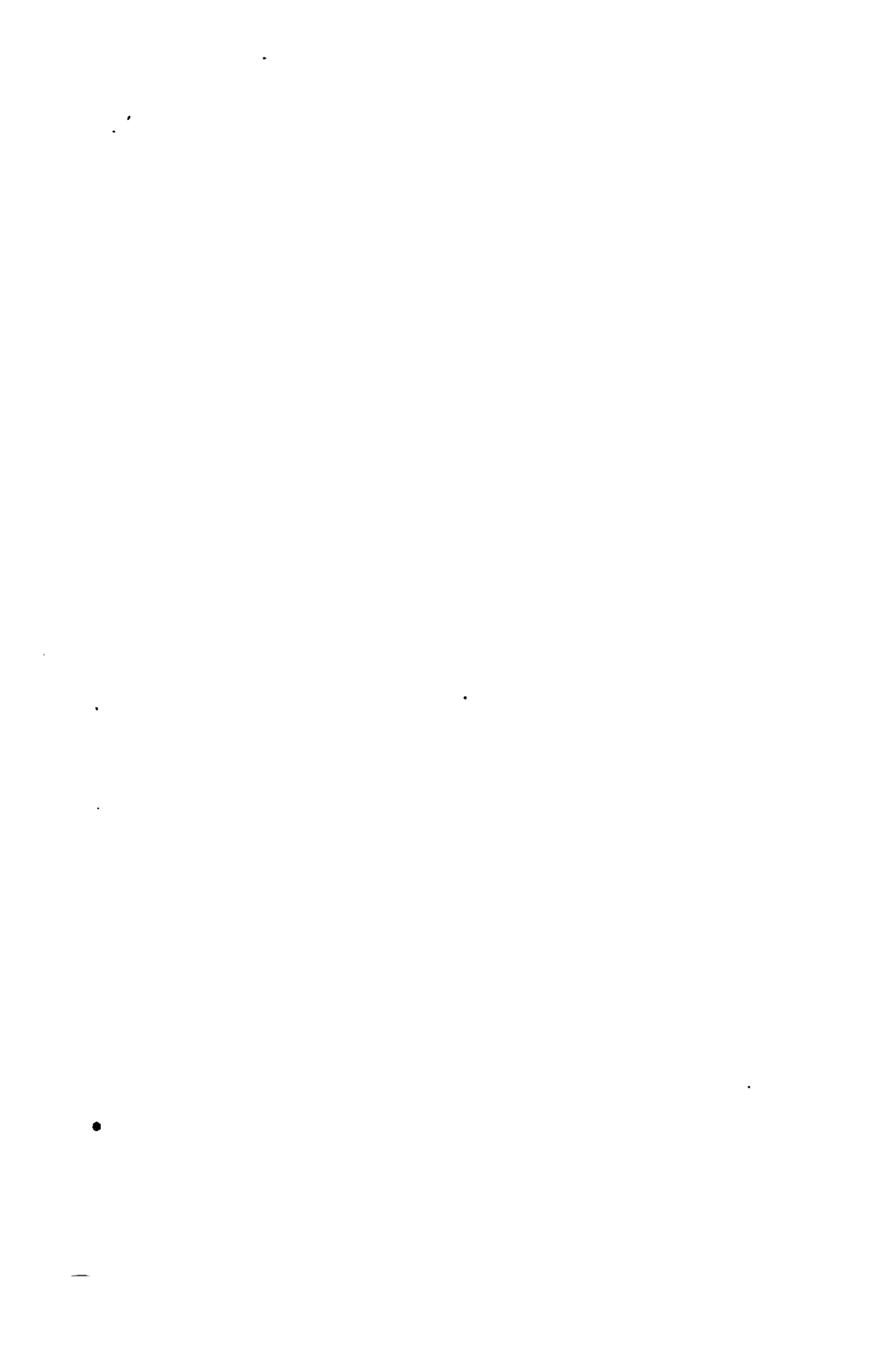
UNEXHAUSTED
TILLAGES AND MANURES,

WITH REFERENCE TO THE
LANDLORD AND TENANT (IRELAND) ACT,
1870.

BY
J. B. LAWES, Esq. F.R.S., F.C.S.

DUBLIN:
JOHN FALCONER, 53, UPPER SACKVILLE-STREET.

1874.



CONTENTS.

	PAGE.
Introduction - - - - -	7
Relation between Landlord and Tenant - - -	10
Unexhausted Tillages - - - - -	12
Manures - - - - -	14
Unexhausted Manures - - - - -	18
1. Manure from purchased Cattle-food - - -	24
2. Farm-yard, or Town-stable Manure - - -	30
3. Rape-cake (or other Cake) used as Manure - - -	32
4. Bones - - - - -	33
5. Nitrate of Soda - - - - -	35
6. Salts of Ammonia - - - - -	37
7. Superphosphate of Lime, made from Mineral Phosphates; and other purely Mineral Manures - - -	37
8. Guano, in its Natural State, or Manufactured - - -	39
9. Other Manures of more or less unknown Composition - - -	42
10. Liming, Chalking, Marling, &c. - - -	46
The Case of Trye v. the Duke of Leinster - - -	47

UNEXHAUSTED
TILLAGES AND MANURES;
WITH REFERENCE TO THE
LANDLORD AND TENANT (IRELAND) ACT, 1870.

INTRODUCTION.

HAVING been summoned as a witness in the case of *Trye v. The Duke of Leinster*, when heard on appeal before the Lord Chief Justice of Ireland, at Naas, last summer, and being present throughout the trial, I was much struck with the great difficulties under which both counsel and judge laboured, for want of some definite rules to guide their inquiries.

The case was the first claim of importance made for compensation under the Act of 1870, for the value of "tillages, manures, or other like farming works, the benefit of which is unexhausted at the time of the tenant quitting his holding." Mr. Trye had entered upon the farm in 1867, as assignee of a lease dating from 1853, and expiring in 1873; and the question was admitted to be, whether, comparing the condition of the land at the expiration of the lease in 1873, with that at the commencement of the term in 1853, a claim for unexhausted tillages and manures could be established.

8 *Unexhausted Tillages and Manures.*

This appeared to me to be a very simple question. Yet the hearing of the case occupied a whole day when tried at the Quarter Sessions before the Chairman of the county of Kildare, and part of three days when heard on appeal before the Lord Chief Justice of Ireland.

The farm comprised something over 136 Irish acres, equal to about 220 statute acres. Technically, the claim put in was in the form of an account of the total expenditure of the tenant on the farm during the six years of his occupation from March, 1867, to March, 1873, amounting to £4,902 10s. 0d., as under :—

	£	s.	d.
Manual labour, tilling, and cultivating farm, .	1,900	0	0
Horse labour, do. do. .	1,200	0	0
Home-made manures, . . .	562	10	0
Artificial manures, . . .	447	0	0
Oilcake, meal, and feeding cattle, .	455	0	0
Buildings, roads, gates, fences, &c., &c., .	338	0	0
	<hr/>		
	£4,902	10	0

The claim actually urged was, however, for something over £1,000 ; and the amount tendered by the defendant was £123 2s. 0d.

Although the dispute was, in this case, between the outgoing tenant and the landlord, it should be remembered that any payment for compensation to an outgoing tenant will, as a rule, eventually fall

upon the incoming tenant. Tenant farmers, as a body, are, therefore, equally with the landlord, interested in the establishment of a fair and equitable basis for the settlement of claims for unexhausted improvements.

It is natural enough that an unsuccessful farmer should consider that the money which he has sunk on a farm he is leaving is so much latent wealth to be taken out by his successor. It by no means follows, however, that because money has been expended there remains a valuable residue within the soil from previous manuring; whilst, in the present state of our knowledge, the determination of the value of any such residue is admittedly a matter of considerable difficulty and uncertainty. Being much impressed with this, I suggested, in a paper on the "*Valuation of Unexhausted Improvements*," read before the London Farmers' Club, on April 4, 1870, that the valuation should be based on the produce, rather than on an estimate of the value of the residue of the manures. My conclusions on the point were summed up briefly as follows:—

"No simple rules, applicable to various descriptions of soil, season, crop, and manure, can be laid down for the valuation of the unexhausted residue of previously applied manures which have already yielded a crop.

“By the valuation of so much of the farm-yard manure, and of so much of the manure-constituents derived from purchased cattle food as have not yet yielded a crop, and also of the straw of the last harvest, fair compensation may be made to the outgoing tenant, whilst the incoming tenant will only be required to pay for that which has a fixed and easily ascertainable money-value.”

In default of the adoption of the principles of valuation above indicated, it may be well, as a contribution towards the settlement of this difficult question, to direct attention to some of the data furnished by my experiments at Rothamsted, as to the amount and condition of the unexhausted residue left in the soil by different descriptions of manure, and to attempt to construct a scale of valuation for different manures, founded partly on those data, and partly on the recognized experience of practical agriculture.

RELATION BETWEEN LANDLORD AND TENANT.

The owner of land, not wishing himself to cultivate it, lets it to some one who is willing to do so, and to pay him annually a sum of money for the use of a house, premises, and a certain number of acres. Either a lease is granted; or the land is let from year to year. At any rate, certain covenants are generally entered into, fixing the course of cropping,

what produce may be sold, what must be consumed on the farm, and so on. In the absence of any such covenants, the ordinary custom of the locality is considered to be binding. The general object of whatever arrangement may be made, is to secure that the land shall be given up in as good a state of cultivation, and condition, as it was when it was entered upon.

It often happens, however, that the tenant considers it his interest to farm the land better than he is bound, either by agreement or by custom, to do. He invests his money in deeper and better cultivation, or in the purchase of cattle-foods or manures, or both. In doing so he doubtless derives benefit himself in the meantime ; but, however long he may stay, if he continue the better cultivation, or a system of importation, to the end of his holding, and does not sell either green crops or dung, he cannot reap the full benefit from his outlay. The better he cultivates the more lasting will be the effects ; whilst a portion of his manures will inevitably stick in the soil. Unlike the tenant of a house, who puts in his own furniture, enjoys the use of it whilst he stays, and removes the whole of it when he leaves, the tenant of a farm cannot carry away with him his unexhausted "tillages and manures." The Irish Landlord and Tenant Law says, therefore—and it is asked that something of the same kind should be said in regard to England and Scotland also—that

the retiring tenant shall receive the value of his unexhausted improvements. In the Act for Ireland, the difficult task of determining what that value is has been imposed upon the judges of the country.

UNEXHAUSTED TILLAGES.

The term "unexhausted tillages" would include all mechanical working of the land by the outgoing tenant, "the benefit of which is unexhausted at the time of the tenant quitting his holding."

In almost all cases, certain acts of husbandry performed by the outgoing tenant are paid for by his successor, in accordance with the provisions of a lease or agreement, or the custom of the locality. In addition to matters so provided for, the Legislature has, in the Irish Land Act of 1870, authorized the outgoing tenant to claim, and receive, compensation for acts of tillage which he was not by his covenants bound to perform, provided he can prove such acts to be of a certain money value to the owner of the land, or to the incoming tenant.

For example, supposing the tenant have held the land under agreement to cultivate it on a five-course shift of roots, barley, seeds, wheat, and oats; but that, after his wheat crop, he finds his land too foul to take oats with advantage, and, therefore, decides to fallow it instead, and in that condition gives up his holding. He would then have had to pay rent, taxes, and all the expenses of cultivating the land,

without any return for this outlay. Under the Irish Land Act of 1870, he can obtain compensation for such expenditure.

A clean fallow, cultivation for a root-crop, subsoil ploughing, and even steam cultivation, each and all may, according to circumstances, be fair subjects for compensation.

Previous to the passing of the Act of 1870, if the out-going tenant gave up a larger number of acres under fallow, or roots, than he entered upon, he would, in justice, have had a claim to compensation, but now the law enables him to enforce it. But whether, if the area so given up be not in excess of that received, he can now establish a claim in regard to such acts of cultivation, must depend altogether upon the construction of the Act, and the decision of the judge accordingly. Subsoil ploughing, or steam cultivation, if undertaken over and above what was required of the tenant by agreement, if any, would also be fair subjects of claim for compensation.

Indeed, in all cases where the circumstances are not specially provided for by lease or agreement, it is not the actual condition in which the farm is given up, as regards unexhausted tillages, but the difference between that condition and the condition in which it was entered upon, that constitutes a fair subject of claim for compensation by the one party or the other.

Land-drainage would obviously be included under the words "tillages, manures, or other like farming works, the benefit of which is unexhausted at the time of the tenant quitting his holding." Such works are, however, seldom undertaken excepting under special arrangement between the landlord and tenant. When the circumstances are not covered by such arrangement, any disputed claim could only be settled on the evidence of those who have made the subject of drainage a special study; and, as the course of my experiments has not afforded me special or varied experience in regard to it, I think it better not to enter into any discussion of the question here.

MANURES.

Before considering the question of unexhausted manures, it will be well to say a few words on the action and value of manures generally, and especially on the difference in the action and value of different descriptions of manure.

The term *manure* includes a great variety of substances, which, when applied to the soil, increase the growth of crops. Formerly, the only manure employed was that produced by animals consuming food, and using litter, which were exclusively the produce of the farm itself. Modern agriculture has greatly altered this state of things. We have now a long list of manures, derived from sources external

to the farm itself, which are in common use by farmers.

The following is an enumeration of the most important of the manures, the unexhausted residues from which are likely to become the subjects of claim for compensation :—

1. Manure produced from purchased (or saleable) cattle food.
2. Farm-yard, or town-stable manure.
3. Rape-cake (or other Cake) used as manure.
4. Bones.
5. Nitrate of Soda.
6. Salts of Ammonia.
7. Superphosphate of Lime, made from mineral phosphates ; and other purely mineral manures.
8. Guano, in its natural state, or manufactured.
9. Other manures of more or less unknown composition.
10. Liming, chalking, marling, &c.

The difference in the price at which the different items of purchased manure in this list can be brought upon the farm is very wide indeed.

By way of illustration, it may be assumed, that town-made dung will, in the majority of cases in which it is largely used, cost the farmer about 7s. 6d. per ton delivered on his farm. Nitrate of soda will, however, cost him at least 15s. per cwt.,

and as a rule more. Thus, he finds it worth his while to give as much, or more, for 1 cwt. of nitrate of soda, as for 2 tons of stable dung; or, in other words, more than 40 times as much for an equal weight of the one manure as of the other.

Sulphate of ammonia is dearer than nitrate of soda; and although it is not purchased to any great extent directly by the farmer, it is much used in the manufacture of mixed artificial manures.

Again, Peruvian guano, when of good quality, contains a considerable quantity of ammonia, as well as phosphates, and costs about £13 per ton; whilst, inferior guano, poor in ammonia but rich in phosphate of lime, and superphosphate of lime, containing no ammonia at all, sell for only about one-third as much.

Nitrate of soda contains its nitrogen as nitric acid, sulphate of ammonia contains it as ammonia, and Peruvian guano also contains, or by decomposition yields, it as ammonia. In fact, the money-value as manure, of nitrate of soda, or sulphate of ammonia, is exclusively, and that of Peruvian guano chiefly, due to the nitrogen they contain.

Thus, it will be seen, that the highest priced manures are those which are rich in nitrogen. A few illustrations may here be given of the effects of nitrogenous manures upon the growth of crops.

Barley has been grown in one field at Rothamsted for more than 20 years in succession. On one por-

tion there has been applied, every year, a mineral manure consisting of salts of potass, soda, and magnesia, and superphosphate of lime; and the average produce over 20 years was $27\frac{1}{2}$ bushels of dressed corn per statute acre. On other portions, there were used, every year, the same mineral manures, with the addition of nitrate of soda, or ammonia-salts, and the average produce then reached very nearly 50 bushels per acre per annum; or nearly double that by the mineral manures used alone. Indeed, the produce obtained by using this mixture of mineral and nitrogenous manure was even rather higher than that yielded by the annual use, for 20 years in succession on the same land, of 14 tons of farm-yard manure per acre.

In an immediately adjoining field, wheat has been grown, without manure, and by different descriptions of manure, for thirty years in succession, and with very similar results. Mineral manures alone have given very little increase of produce; nitrogenous manure alone, in the form of nitrate of soda or ammonia-salts, has given considerably more produce than mineral manure alone; and the mixture of mineral and nitrogenous manures has yielded more, of both corn and straw, than the annual application of farm-yard manure.

Thus, then, not only are those manures which are rich in nitrogen the highest priced, but direct experiments, extending over a long series of years,

have shown that nitrogen has, in reality, a higher money-value for the purposes of manure than any of the other substances used.

It will be seen further on, how much the settlement of all questions of compensation for unexhausted manures must depend upon the estimate formed of the amount, and the condition, of the nitrogen of the manure remaining in the soil ; and how much this, in its turn, must depend on the description of the manure employed, the character of the soil to which it has been applied, the characters of the seasons, and the kinds of crop which have been grown since the application.

UNEXHAUSTED MANURES.

When a manure is applied to the soil, what happens ? This point may be illustrated very usefully for our present purpose by reference to direct results obtained at Rothamsted.

To certain plots, given quantities of salts of potass, soda, and magnesia, superphosphate of lime, and salts of ammonia (or nitrate of soda), have been applied every year ; and, for between 20 and 30 years, full crops of wheat and of barley have been obtained under this treatment.

Analysis of the produce has shown, that a large proportion of the nitrogen supplied in the manure has remained unrecovered in the increase of the crop produced by its use. Still, any reduction in

the quantity annually applied was followed by a diminution in the amount of the crop ; or, if the application were entirely stopped, there was frequently little or no effect upon succeeding crops from any unexhausted residue.

Analysis of the soil showed, that a portion of the nitrogen of the manure which was not recovered in the increase of crop was accumulated within the soil ; but, that there yet remained a large amount of the supplied nitrogen to be otherwise accounted for than either in the crop or in the soil.

It was next determined that the drainage-water from the various plots of the experimental wheat field, which was already pipe-drained, should be examined. Numerous analyses of the drainage-water from the differently manured plots, collected at different periods of the year, have, by their own desire, been made, independently, by Professor Voelcker, and by Professor Frankland. Their results proved—that the drainage-waters frequently contained a large amount of nitrogen in the form of nitrates ; that the quantity of nitrates was the greater the greater the amount of ammonia-salts applied as manure ; and that (after autumn sowing) the quantity was very much greater in the winter, than subsequently in the spring and summer.

In one case, after a heavy dressing of ammonia-salts, Dr. Frankland found a quantity of nitrates in the drainage-water, which would correspond to a

loss of nearly 18 lbs. of nitrogen per statute acre, provided an inch of rain had passed as drainage of that strength. On another occasion, after a heavy dressing of nitrate of soda, Dr. Voelcker found a quantity of nitrates in the drainage-water, which, reckoned in the same way, would be equivalent to a loss of about 13 lbs. of nitrogen per acre.

Lastly, on this point, calculation led to the conclusion, that most probably the whole of the nitrogen which had been supplied as manure in the ammonia-salts, or nitrate of soda, and which was not either recovered in the increase of crop, or retained by the soil in a very slowly available condition, was drained away and lost.

When the manure employed contains, or yields, ammonia, what happens is, that the ammonia becomes oxidated in the soil, and so converted into nitric acid, which is washed away in the drainage-water, chiefly in combination with lime, or soda, or both, if not in the meantime taken up by a growing plant. When, however, nitrate of soda is applied, its great solubility, and the much less power of the soil for the absorption of it, or of its products of decomposition, than for that of ammonia, render it extremely liable to loss by drainage if heavy rain should follow soon after sowing.

Although the *nitrogen* of manures is thus found to be very liable to loss by drainage, direct experiments show that the two important mineral con-

stituents, *phosphoric acid* and *potass*, are much less liable to such loss.

Thus, Dr. Voelcker's analyses of the drainage-waters showed them to contain very little of either phosphoric acid or potass ; and analyses of the soils themselves, made by Hermann von Liebig, son of the late Baron Liebig, showed that they contained considerably more of both phosphoric acid and potass—especially in the upper layers—the greater had been the supplies of them by manure. Experiments in the field further showed that these substances, though remaining dormant and ineffective in the soil in the absence of a sufficient supply of nitrogen, become effective, even for 20 years, or more, after their application, if nitrogen in an available form be also provided within the soil.

It is proved, then, that of the three constituents of manures—*nitrogen*, *phosphoric acid*, and *potass*—(which, in the sense that, by the production and sale of corn and meat, they are the most likely to become relatively deficient, are the most important constituents of manures generally) the nitrogen is, at any rate when applied as ammonia-salts or nitrate of soda, very liable to loss by drainage, whilst the phosphoric acid and potass are, in a much greater degree, retained by the soil.

When farm-yard manure is employed, or other manures containing a large quantity of nitrogenous

organic matter are used, the result is not quite so simple. For example, in farm-yard manure, a portion of the nitrogen exists as ready-formed ammonia, but a large proportion becomes only very gradually converted into ammonia as the nitrogenous organic matter decomposes in the soil. Indeed, owing to the slow decomposition of dung, and the tardiness with which a large proportion of its nitrogen becomes available for the use of the growing crop, three or four times more nitrogen, in the form of dung, than in active artificial manures, must be applied to produce the same effect upon the immediately succeeding crop.

Dung, however, possesses two very important properties, one mechanical and the other chemical. By reason of its bulk, and the quantity of organic matter it contains, it serves to render the soil more open and porous, and so to enable it, not only to retain more water in a favourable condition, but also to absorb and retain more of the valuable constituents of the manure, and so to arrest the passage of them in solution into the drains. Further, by the gradual decomposition of the organic matter of the dung, the pores of the soil become filled with carbonic acid, which probably serves to retard the oxidation of the ammonia into the more soluble form of nitric acid, in which it would be more liable to be washed out and lost by drainage. From these facts it will be readily understood how it is that dung is

more lasting in its effects than the more active artificial manures.

Still, in the experiments at Rothamsted, in which dung has been applied year after year for many years in succession, there is a large amount of the nitrogen so supplied, which is not yet accounted for, either in the increase of crop, or in the soil. Whether there is an ultimate loss of a greater or less proportion of that supplied than when ammonia-salts or nitrate of soda is used; whether the loss will be proportionally the same when dung is used in more moderate quantity; or whether the loss be wholly, or chiefly, by drainage, or in other ways, the evidence at present at command is not sufficient to determine with certainty.

From the foregoing observations on the characteristics of some of the most important descriptions of manure, it will be obvious how essential it is to take into careful consideration the peculiar properties, and probable duration of effect, of different manures, if we would hope to arrive at anything like a fair estimate of the money-value of the unexhausted residue they leave in the soil under various circumstances.

Guided by such knowledge as I possess on the various essential points of the question, I will now endeavour to estimate the value of the unexhausted residue of various manures, under the circumstances in which that value is most likely to become the

subject of claim for compensation. In all cases, the valuation is expressed in the number of shillings estimated to be due to the out-going tenant, for twenty shillings original manure-value. The valuations given must, however, be taken as only approximately correct; as the amounts due might be affected, to the extent of 20 per cent., or more, according to the cleanliness or foulness of the land, the lightness or heaviness of the soil, the dryness or wetness of the seasons, and the difference between the purchasing price of the food or manure and its actual and relative value.

1.—*Manure from purchased Cattle-food.*

Claims for compensation for unexhausted manures will probably arise more frequently under this head than under any other. It will be necessary, therefore, to consider the question in some detail.

When the farmer uses purchased cattle-food, or food the produce of the farm which he would otherwise be justified in selling, he looks for his remuneration, partly to the increased value of his animals, and partly to the value of the manure obtained from them. The increased value of the animals is of itself seldom, if ever, equal to the cost of the food consumed. Unless, therefore, the out-going tenant can rely upon obtaining compensation for the value of the manure produced from such food, he must either cease to purchase it, and feed

his animals on the produce of the farm alone for a year or two before he leaves it, or he must submit to a loss which sometimes will be very considerable.

Before we can approach the question of the value of the *unexhausted residue* of manure produced by the consumption of purchased (or saleable) cattle-food, it is necessary to come to some decision as to the original value of such manure; in other words, to determine how much of the cost of any particular food should be charged to the manure account.

With regard to the value of different foods for feeding purposes, it may be stated in general terms, as the conclusion drawn from hundreds of feeding experiments with different descriptions of food, made at Rothamsted, that, weight for weight, there is very much less difference in the *feeding-value* than in the *manure-value* of foods which are included in what may be called the same class. For instance, it will make comparatively little difference, so far as the increase in the live-weight of the animal is concerned, whether a ton of cake, a ton of pulse, a ton of Indian meal, or a ton of barley, be given to fattening oxen or sheep; and comparatively little whether a ton of clover-hay, or a ton of meadow-hay, be used. Within each of these classes of food, however, there would be a very wide difference in the value of the manure which the consumption of a ton of each of them would produce.

Having regard to the results of the feeding

experiments above referred to, and taking into consideration the known average composition of different descriptions of food, an estimate was made of what proportion of certain of the constituents in a ton of various descriptions of food would, on the average, be stored up in the animal itself, and what proportion would be obtained in the manure produced. The value for manure of those constituents was then calculated, and the results are given in the following Table, which I first published about 14 years ago:—

TABLE.—*Estimated Value of the Manure obtained by the Consumption of different Articles of Food, each supposed to be of good quality of its kind.*

Description of Food				Money value of the Manure from one Ton of each Food		
				£	s.	d.
1	Cotton-seed Cake, decorticated,	...	...	6	10	0
2	Rape Cake,	...	...	4	18	6
3	Linseed Cake,	...	...	4	12	6
4	Cotton-seed Cake, not decorticated,	...	...	3	18	6
5	Lentils,	...	...	3	17	0
6	Beans,	...	...	3	14	0
7	Tares,	...	...	3	13	6
8	Linseed,	...	...	3	13	0
9	Peas,	...	...	3	2	6
10	Indian Meal,	...	...	1	11	0
11	Locust Beans,	...	...	1	2	6
12	Malt dust,	...	...	4	5	6
13	Bran,	...	...	2	18	0
14	Coarse Pollard,	...	...	2	18	0
15	Fine Pollard,	...	..	2	17	0
16	Oats,	...	...	1	15	0
17	Wheat,	...	...	1	13	0
18	Malt,	...	...	1	11	6
19	Barley,	...	...	1	10	0

TABLE—continued.

Description of Food					Money value of the Manure from one Ton of each Food.		
					£	s.	d.
20	Clover Hay,	...	...	...	2	5	6
21	Meadow Hay,	...	...	...	1	10	6
22	Bean Straw,	...	...	...	1	0	6
23	Pea Straw,	...	...	...	0	18	9
24	Oat Straw,	...	...	...	0	13	6
25	Wheat Straw,	...	...	...	0	12	6
26	Barley Straw,	...	...	...	0	10	9
27	Potatoes,	...	...	...	0	7	0
28	Parsnips,	...	...	...	0	5	6
29	Mangold Wurtzel,	...	...	...	0	5	3
30	Swedish Turnips,	...	...	...	0	4	3
31	Common Turnips,	...	...	...	0	4	0
32	Carrots,	...	...	...	0	4	0

The prices given in the foregoing table represent what it will be convenient to term the *manure-value* of a ton of the different descriptions of food ; that is to say, the value of the manure provided it reached the soil without loss, and was not subject to loss by drainage before the growth of a crop. These prices might conveniently be adopted as a basis in the settlement of claims for compensation for the unexhausted residue of manure derived from the consumption of purchased or saleable cattle-foods.

Any one acquainted with the cost, and the feeding value, of the different foods, will see, by a glance at the Table, how little connexion there is between either the cost, or the feeding value, of a ton of

the different foods, and what may be termed their *manure-value*.

It is clear, therefore, that it would be quite fallacious to base a claim for compensation for the unexhausted manure from purchased food, either upon the number of tons of food consumed, regardless of the description of that food, or upon the amount of money expended in its purchase. For example, the cost of a ton of undecorticated cotton-cake, and of a ton of locust-beans, would be much about the same ; but the table shows that the estimated value of the manure from the consumption of a ton of the cotton-cake would be £3 18s. 6d., whilst that from a ton of locust-beans would be only £1 2s. 6d. Hence, the same outlay—according as a ton of the one or of the other of these two descriptions of food were purchased—would result in a difference of £2 16s. in the value of the manure thereby brought upon the farm.

The *manure-value* alone should, therefore, be adopted as the basis of any calculations of the value of the unexhausted residue of manures derived from the consumption of purchased or saleable cattle food.

Adopting the *manure-value* of the different foods, as given in the table, I will now endeavour to estimate, to the best of my ability, the value of the unexhausted residue of such manures, under various circumstances which are likely to occur.

When the ordinary manure of the farm is enriched

by the consumption of purchased or saleable cattle foods, the first crop grown after the application of such manure will be considerably increased. The second and third crops will, according to circumstances, be more or less benefitted; but, practically speaking, there will be no unexhausted residue left at the end of the rotation.

If purchased food be consumed with a root crop, and the out-going tenant take no crop grown by the manure so produced, he should be allowed compensation at the rate of 17s. for every 20s. of the original *manure-value* of the food if it have been consumed on the land, or of only 16s. if consumed in the yards. If he take one corn crop produced by such manure, sell the corn, but leave the straw on the farm, he should be allowed 7s. for every 20s. of the original *manure-value* of the purchased or saleable food. If he have taken a second corn crop, leaving the straw, he should be allowed 1s.; or if, instead of a second corn crop, grass or hay be grown and consumed on the farm, 2s.; but if the second crop, after the roots, be hay which he has sold, nothing should be awarded to him.

If purchased or saleable food be consumed on grass land, and the out-going tenant have not afterwards removed a crop of hay, he should be allowed 18s. for 20s. original *manure-value* of the food. If he have taken one crop of hay, and consumed it on the farm, he should be awarded 11s., but if the hay

have been sold, only 2s. for 20s. of the *manure-value* of the food. After a second year's hay crop, if consumed, 2s., but if sold nothing, should be allowed. If the land be only pastured, and purchased food be consumed on it for one, two, or three years before leaving, the compensation might fairly be fixed at 18s. for 20s. original *manure-value* after one year, at 12s. after two years, and at 4s. after three years.

2.—*Farm-yard, or Town-stable Manure.*

Farm-yard manure, made from the produce of the farm alone, without purchase of cattle food, should not be made the subject of any claim for compensation by the out-going tenant, whether such manure have grown a crop, or remain in the yards, or on the land. The cases of the enrichment of such manure by the use of purchased cattle food, would be taken into account under the provisions of the previous section.

When stable manure is purchased and used in large quantities, and the application has extended over a long series of years, as, for instance, in the case of garden ground, the unexhausted residue remaining in the soil is very great, and large crops may be taken from such land, without further manuring, for a number of years in succession. Such cases would require special consideration and adjudication, if not provided for by special agreement, as generally would be the case.

When purchased stable manure is only used in the moderate quantity usual in ordinary agriculture, and only once in the course of a rotation of 4 or 5 years, it may be assumed that towards the end of such period no unexhausted residue would remain which would be sufficient to justify a claim for compensation to the out-going tenant.

If purchased stable manure be applied for roots which are consumed on the land, 17s. for every 20s. of the original value of the manure may be allowed, but if the roots be consumed in the yards, only 16s. If one corn crop be afterwards taken, the corn sold, but the straw left on the farm, 9s. may be allowed ; if a second crop have been taken, the corn sold, but the straw left, 3s. should be allowed ; or if, instead of a second corn crop, grass or hay be grown and consumed one year, 5s. ; but if the hay be sold, or the grass have been grazed a second year, only 2s. should be allowed.

If such manure be applied directly for a corn crop, the corn sold, and the straw left, 12s. for 20s. of the original value of the manure may be awarded. After a second corn crop, 6s. ; or if, instead of a second corn crop, grass or hay be grown and consumed one year, 8s. ; or if the first year's hay be sold, or the produce grazed or consumed a second year, only 4s. should be allowed.

If the manure be applied directly to grass land, and the produce is entirely grazed, 18s. may be

allowed after one year; 14s. after two years; 8s. after three years; and 2s. after four years. If the manure be applied to grass land, and hay be taken exclusively for consumption on the farm, the allowance should be 16s. after one year, 12s. after two years, and 6s. after three years; or, if the hay be sold, 10s. after one year, 4s. after two years, but nothing after three years, should be allowed.

3.—*Rape-Cake (or other Cake) used as Manure.*

When rape-cake, or other cake, is used as manure, a considerable portion of it decomposes pretty rapidly in the soil, and the more so the lighter and more porous the soil. It yields up a much larger proportion of its nitrogen, and other manurial constituents, in the first year of its application, than does farm-yard manure; and, accordingly, in practice, a quantity not containing one-fourth the amount of nitrogen of an ordinary dressing of dung would be applied to produce the same effect on the first crop. An ordinary dressing of rape-cake, therefore, after the first crop, leaves a very much less unexhausted residue than an ordinary dressing of dung. A given quantity of nitrogen applied as rape-cake, would, on the other hand, be less rapidly available and effective, than the same quantity applied as nitrate of soda, sulphate of ammonia, or Peruvian guano; but it would be less liable to loss by drainage, and would, therefore, leave a larger proportion as unex-

hausted residue after the first crop, than either of the above-named more rapidly active manures.

If the out-going tenant have applied cake as manure for a root-crop, and the roots have been consumed on the farm, he should receive compensation at the rate of 16s. for 20s. cost of the manure if they were consumed on the land, and of 15s. if consumed in the yards. If a corn crop have been grown after the roots, the corn sold, and the straw left, he might receive 7s. for 20s. cost of the manure ; if a second corn crop, 1s. ; or if, instead of a second corn crop, grass or hay be grown and consumed, 3s. ; but if hay be sold, nothing should be allowed.

If cake be applied directly for a corn crop, the corn sold, and the straw left, 7s. for 20s. cost of the manure may be allowed. If a second corn crop have been taken, 1s., but if a third, nothing should be allowed. If instead of a second corn crop, grass or hay be grown and consumed, after one year, 3s., or after two years, 1s. ; but if hay be sold, nothing should be awarded.

4.—*Bones.*

Ordinary crushed or half-inch bones decompose less rapidly, and are, therefore, less rapidly active, than finely-ground bones. In either state, bones are less rapidly active than rape-cake ; and, like rape-cake, are much less so than nitrate of soda, ammonia-salts, or guano. The action of bones depends, more-

over, very much upon the characters of the soil to which they are applied. In heavy soils their action is very slow, and, therefore, the more lasting; but in light soils it is more rapid, and less lasting.

In the case of soils to which experience has shown that bones can be applied with effect and profit for the root-crop, if so applied, and no crop have been grown from the manure produced by the consumption of the roots, the allowance might be 17s. for 20s. original value, if the roots have been consumed on the land, or 16s. if consumed in the yards. If a corn crop have been taken after the roots, the corn sold, and the straw left, 8s. ; if a second corn crop, 2s. ; if, instead of a second corn crop, grass or hay be grown and consumed one year, 4s. ; or if hay be sold, or grass or hay consumed a second year, only 1s. should be allowed.

If bones be applied to suitable grass land, which is entirely grazed, 18s. for 20s. original value may be allowed after the first year, 13s. after the second, 6s. after the third, and 1s. after the fourth year. If the grass be made into hay and consumed on the farm, 16s. after one year, 10s. after two years, and 3s. after three years, may be allowed. If the hay be sold, 10s. may be allowed after the first year, 4s. after the second, but nothing after the third year.

5.—*Nitrate of Soda.*

From what has been already said of the loss of the nitrogen of manure by drainage, and especially of the very great loss that may arise when such soluble and rapidly active nitrogenous manures as nitrate of soda, or ammonia-salts, are used, it will be readily understood that, when they are employed, we have not to look forward very far to reach the limit of their action, and, consequently, the period at which any claim for compensation for their unexhausted residue should cease. This point is, in fact, sooner reached in their case than in that of any other nitrogenous manures. Next in order, in lasting character, so far as the nitrogen is concerned, comes guano, then perhaps folding, then rape-cake, and then bones; whilst farm-yard manure is the most lasting of all.

Notwithstanding the very great solubility of nitrate of soda, and its greater liability to loss by drainage than any other nitrogenous manure, some experiments at Rothamsted have shown that, after it had been used in large quantities for many years in succession, considerable benefit accrued to future crops. To what extent this result was due to the disintegration of the subsoil, by which it became more porous, more capable of retaining water in a condition favourable for the growing crop, and more permeable to its roots, and how much to the retention of nitric acid by virtue of the increased porosity, and

therefore surface for absorption of the subsoil, there is not sufficient evidence to show. It would, indeed, be quite unsafe to assume that any conclusions applicable to ordinary practice can be drawn from these results, obtained under such exceptional circumstances.

It must, in fact, for practical purposes be assumed, that nitrate of soda, used only occasionally, and only in the moderate quantities usually applied, leaves no beneficial residue after the removal of the first crop. Whatever is not taken up by the crop itself, or washed out during its growth, will probably be, in great part, drained away in the winter following, leaving at any rate but a small, an uncertain, and a doubtfully effective, residue.

When nitrate of soda is applied for a corn crop, the grain sold by the out-going tenant, and the straw left on the farm, he should receive 6s. for 20s. cost of the manure; nothing after a second corn crop; but if, instead of a second corn crop, grass or hay be grown and consumed, 1s.

If nitrate of soda be applied to grass which is only pastured, 16s. for 20s. of original value of the manure should be allowed after one year, 10s. after two years, and 2s. after three years; if hay be taken and consumed, 14s. after the first year, 8s. after the second year, and 1s. after the third year; but if the hay be sold, 2s. after one year, but nothing afterwards, should be allowed.

6.—*Salts of Ammonia.*

The only salt of ammonia used to any extent for agricultural purposes is the sulphate of ammonia. As already said, this is used to a considerable extent ; but chiefly in the manufacture of mixed manures. When sown in the autumn, it will be more liable to loss by drainage than nitrate of soda sown in the spring ; but when sown in the spring, it will probably be less liable to loss by drainage than nitrate of soda sown at the same time. It is more liable to such loss in the case of light and porous soils and subsoils, than of soils and subsoils of more retentive character.

The same rules for compensation will be applicable to sulphate of ammonia as to nitrate of soda ; provided the circumstances of its application, as above referred to, be the same.

7.—*Superphosphate of Lime, made from Mineral Phosphates ; and other purely Mineral Manures.*

It has been explained that the phosphoric acid, and the potass, of manures of this class, are comparatively little liable to loss by drainage, at any rate when applied to the heavier soils. In fact, they leave a considerable unexhausted residue ; but that residue is, as a rule, without appreciable effect on succeeding crops, unless nitrogenous manure be applied to take it out. If, therefore, the crop for which the manure has been applied, has been wholly

sold by the out-going tenant, no residue will remain to which a money value can be assigned.

The most prominent effect of superphosphate of lime, when applied to a root crop, is to cause a great development of root-fibres, thus enabling the plant to gather up much more of other food from the soil. It, therefore, serves to increase the immediate effect of other manures supplied with it; also to turn to account accumulations within the soil, which, if not taken up, would be liable to loss by drainage.

When superphosphate has been applied to roots, and no crop has been taken from the manure produced by their consumption, 9s. for 20s. of its cost may be allowed if the roots be consumed on the land, or 8s. if in the yards; or, if corn follow the roots, the grain sold and the straw left, 2s. may be allowed.

When superphosphate has been applied for a corn crop, the corn sold and the straw left, compensation to the extent of 5s. for 20s. cost of the manure might be granted.

No compensation should be claimed for the unexhausted residue of superphosphate, or other purely mineral manures, whenever a second crop of any kind has been taken since the application, excepting corn after roots as above specified.

8.—*Guano, in its natural state, or manufactured.*

Under the existing conditions of the Peruvian Guano Trade, it is impossible to speak with any certainty even as to the value of guano as a direct manure. It must, therefore, be more difficult still to speak definitely as to the value of the residue it may leave in the soil after the removal of a crop.

At one time the farmer could calculate upon receiving guano containing nitrogen equal to 16 per cent. of ammonia; more recently he had to be satisfied with 14 per cent.; and more recently still, not only a lower average per cent. than this, but great uncertainty whether he would receive that amount, half as much, or even less.

At the present time, the agents of the Peruvian Government sell some of their guano in its natural state, which, on the average, probably contains nitrogen equal to about 12 per cent. of ammonia, and from 25 to 30 per cent. of phosphates; but some they mix with sulphuric acid, and manufacture it into a substance of uniform quality, containing nitrogen equal to about 10 per cent. of ammonia, superphosphate equal to about 20 per cent. of phosphate rendered soluble, and only about 4 per cent. of phosphates left undissolved.

Such a manufactured guano would rank in a position intermediate between the more highly and purely nitrogenous manures (such as nitrate of soda

and sulphate of ammonia) on the one hand, and a superphosphate of lime on the other; or, rather, it would be equivalent to a mixture of the two.

Other manure-dealers also prepare "dissolved guano," but of very varying composition.

From what has been said in regard to the action, and the value, of different descriptions of manure, it will be readily understood that the value of guano will depend very greatly upon the percentage of nitrogen it contains. The nitrogen in guano, whether "dissolved" or not, should be valued at the same rate as that in nitrate of soda, or sulphate of ammonia.

If the guano have been "dissolved," by admixture with sulphuric acid, the value of the phosphates rendered soluble may be reckoned as the same as that in superphosphate of lime, but if not dissolved at only two-thirds as much.

Thus, it will be obvious, that the mere price paid for guano cannot be accepted as the basis upon which to calculate the value of its unexhausted residue after it has yielded a crop. It is essential for the establishment of a claim for compensation, that the composition of the guano should be known, and its actual value calculated, according to—the amount of ammonia it contains or yields, the amount and condition of its phosphates, the price of ammonia in sulphate of ammonia, and that of soluble phosphate in superphosphate.

If the guano have been acted upon by sulphuric acid, both its nitrogen and its phosphates will probably be more effective on the first crop, and leave, therefore, the less for succeeding crops, than if it were used in its natural state. But the difference would not be either sufficiently great, or sufficiently uniform on various soils, and in various seasons, to justify a difference in the scale of valuation of the unexhausted residue.

If guano, whether dissolved or not, have been used for roots consumed upon the farm, and the manure so produced has not yielded a crop, 15s. for 20s. estimated value of the guano may be allowed if the roots be consumed on the land, or 14s. if in the yards. If the manure produced from the roots have yielded a corn crop, the corn being sold, and the straw left, 4s. for 20s. value of the guano should be allowed; if a second corn crop have been taken, 1s.; or if, instead of a second corn crop, grass or hay be grown and consumed, 2s.

If guano, whether dissolved or not, have been directly applied for a corn crop, the grain sold, and the straw left, 6s. for 20s. value of the guano might be awarded. If, after one corn crop, grass or hay be grown, and consumed on the farm, 1s. may be allowed; but if a second corn crop be taken, or hay be cut and sold, no claim for compensation should be admitted.

If guano be applied to grass land, 16s. for 20s.

original value may be allowed after one year, 10s. after two years, and 2s. after three years, if the produce be only grazed; if it be made into hay which is consumed, 14s. after one year, 8s. after two years, and 1s. after three years; or, if a crop of hay be taken and sold, only 2s. should be allowed.

9.—*Other Manures of more or less unknown composition.*

Under this head may be included—Special grass-manures, corn-manures, root-manures, or other compound artificial manures; also, dried blood, shoddy, and some other refuse matters.

As in the case of guano, so in that of each of the above manures, the mere price paid for it cannot be accepted as the measure of its value. If any claim for compensation for the unexhausted residue of such manures is to be made, it is absolutely essential that the composition of the manure used should be known.

It is obviously requisite that any Act by which power is given to an out-going tenant to claim compensation for unexhausted manures, should give the person subject to such claim power to ascertain the composition and value of the manures in respect to which the claim is made. In all cases, therefore, in which it is intended to put in such a claim, the person making it should be required to give notice to the landlord that he is about to use certain

manures, from which he may have samples taken for analysis if he desire it.

Professor Cameron has, from time to time, drawn attention to the numerous frauds committed upon tenant-farmers in Ireland, by the sale of spurious manures; and if a purchaser do not take the trouble to protect himself from fraud when his own interest alone is concerned, he is little likely to do so if, by afterwards claiming compensation based upon the amount of his outlay, he can shift a portion of the loss upon some one else.

The value of the manures of this class will depend almost exclusively on the quantity, and the condition, of the nitrogen, and of the phosphates, which they contain.

Special grass, corn, root, or other compound manures, will sometimes contain their nitrogen as sulphate of ammonia, but frequently in the form of shoddy, or other nitrogenous organic matter. If the nitrogen exist as sulphate of ammonia, it should be valued at the same rate as in that substance. The nitrogen in shoddy, and in most other nitrogenous organic matters used as manure, is, however, much more slowly effective than that in nitrate of soda, sulphate of ammonia, or guano. As a rule, therefore, the nitrogen of manures which exists as nitrogenous organic matter, should be valued at only from one-half to two-thirds the price of that in nitrate of soda, sulphate of ammonia, or guano.

A given quantity of nitrogen in nitrogenous organic matter, being less rapidly effective, and probably less liable to loss by drainage also, than that in nitrate of soda, sulphate of ammonia, or guano, will, of course, leave proportionally more for succeeding crops. The result will, however, be so dependent on the description of the organic matter employed, the kind of soil to which it is applied, the characters of the seasons, and other circumstances, and the residue itself would, in some cases, be so slowly available, that, practically speaking, the unexhausted residue from nitrogenous organic matter applied as manure, cannot be taken at a higher value in proportion to the original value of the manure, than in the case of the more rapidly active nitrogenous manures.

The phosphate of manures of this class, if in the state of superphosphate, should be valued as in superphosphate.

The following scale of compensation for unexhausted residue might be adopted when any of these manures are used.

When applied to grass, and the produce has been only grazed, 16s. for 20s. original value of the manure, calculated as above, may be allowed after the first season, 6s. after the second, but nothing after the third. If hay be taken and consumed on the farm, the allowance may be 13s. after the first year, and 4s. after the second year ;

but if the hay have been sold, only 2s. should be allowed.

When applied for a corn crop, the corn being sold and the straw left, 6s. for 20s. estimated value of the manure should be allowed. If a second corn crop be taken, no allowance should be made; but if, instead of a second corn crop, grass or hay be grown and consumed, 1s. may be allowed.

When applied for a root crop, the roots consumed upon the farm, and the manure so produced have not yielded a crop, 12s. for 20s. of the value of the manure may be allowed if the roots be consumed on the land, or only 10s. if consumed in the yards. If a corn crop have been grown by the manure of the consumed roots, the grain sold, and the straw left on the farm, 2s. for 20s. of the estimated value of the manure should be allowed.

In the case of any compound, or refuse, artificial manure, containing very little nitrogen, but a fair amount of soluble phosphates, the same proportion of the estimated value of the manure may be allowed for unexhausted residue, as if it were a superphosphate. But, if it contain very little of either nitrogen or soluble phosphates, no allowance whatever should be made for its use.

The foregoing remarks as to the circumstances to be taken into consideration in valuing the unexhausted residue of the various compound, or refuse, artificial manures, of more or less unknown,

or uncertain, composition, and the scales of compensation which have been suggested, will, it is hoped, serve as some guide to those who may have to adjudicate on claims made in relation to such manures. At the same time, it will be obvious that, owing to the great difference in the composition and value of such manures, no absolute rules can be laid down for the estimation of the value of any residue they may leave in the soil.

10.—*Liming, Chalking, Marling, &c.* .

Liming, chalking, and marling, are practices so far from being generally required, or generally adopted, in agriculture, and their cost and value are so dependent on local circumstances, that no general rules can be laid down for the valuation of their unexhausted effects. Still, where beneficially adopted, they would undoubtedly be fair subjects for compensation, if the benefits were not exhausted at the time of the tenant quitting his holding. If disputed, any claim should be settled upon the evidence, or might appropriately be submitted to the arbitration, of intelligent and disinterested persons of local practical experience.

THE CASE OF TRYE *v.* THE DUKE OF LEINSTER.

I will conclude with a few observations on this case, which, as has been already stated, was the first claim of importance made for compensation under the "Landlord and Tenant (Ireland) Act, 1870," for the value of unexhausted tillages and manures, both natural and artificial. When the amount and character of the evidence adduced at the two trials, the ability displayed by counsel, the great care bestowed on the subject by the judges, and the large amount of time and money expended, are taken into consideration, there can be little doubt that the case will stand as a representative one for a long time to come.

The real amount of the claim for unexhausted tillages and manures, when separated from the other items included in the statement, amounted to about £1,170, the farm comprising 136 Irish, equal to about 220 statute, acres. A witness of much experience, called by the plaintiff, stated that he had made a field-to-field examination of the farm, and that his estimate of the value of the unexhausted tillages and manures left by the out-going tenant was £708.

Both on the trial before the Chairman of Quarter Sessions, and at the hearing of the appeal before the Lord Chief Justice of Ireland, a large portion of the time was occupied in the examination of the plaintiff

and his witnesses, to prove the money value of the unexhausted tillage and manures of each separate field. At the latter trial, I took very careful notes of this evidence, and have since verified them by comparison with the printed report of the trial.

I propose, first, to select one or two fields for the purpose of illustration, to direct attention to the evidence adduced in support of the claim for compensation in regard to them, and to point out in what respects such evidence was defective. I will afterwards endeavour to show, how the objects for which the trial was instituted could have been much more readily, and much more satisfactorily, attained.

Field No. 1 was stated to have been cropped and treated as follows :—

1868—Turnips; manured with $\frac{1}{2}$ -inch bones.

1869—Barley; sown down with grass seeds.

1870—Meadow; after the hay, liquid manured.

1871—Pasture; fed by sheep.

1872—Pasture; fed by sheep.

Mr. Trye's claim for unexhausted tillages and manures in the case of the field so treated was £10 per acre; and the estimate of one of his most experienced witnesses was £8 per acre.

The plaintiff was asked as to the quantity of liquid manure applied. His answer was that it would be impossible to calculate it, but he after-

wards said it might amount to 200,000 gallons over the whole field, which comprised rather more than 10 acres Irish.

Now, assuming that the question was to be decided by field-to-field examination in this way, the evidence as to this field, No. 1, was defective for such a purpose in several points of view.

1. It was not stated whether the turnips were consumed in the field, or removed into the yards or elsewhere.

2. Nothing was stated as to the quantity of hay removed.

3. The composition of the liquid manure was not even inquired into, and there was great uncertainty as to its quantity.

4. It was not stated whether the animals fed on the pasture received, besides the grass, any purchased food or not.

5. No evidence was either sought or given, as to whether the animals were confined entirely to the field, so that it received the whole of their droppings, or whether they were, at night or at other times, removed into the yards or to other fields.

It is obviously impossible, in the absence of evidence on these points, to form any valid estimate of the value of the unexhausted manures left in the soil of this field at the end of 1872.

I will now take fields Nos. 7, 8, and 9, said to comprise 28 acres Irish (equal rather over 45

statute acres), of which the treatment had been as follows :—

1870—Fallow.

1871—Oats.

1872—Turnips ; artificial manured.

In the Spring of 1873, the landlord entered upon the farm, and sowed these fields with barley, with artificial manure. Mr. Trye's claim for unexhausted tillages and manures in respect to this land, was £10 per acre ; and his principal witness, a practical farmer of great experience, already referred to, gave the following evidence in regard to these fields :—

“They were in barley. It had been tilled too late—badly tilled and badly soiled (sown ?) : but the estimate I formed on those fields was £9 an acre, and £6 an acre for the succeeding crop. There would be unexhausted tillage and manures in the land, after the £9 an acre crop had been taken, to the amount of £6, on the succeeding crop of the meadow. It would, in other words, after the barley, give a crop of meadow next year worth £6 an acre.

“THE CHIEF JUSTICE.—I am not so sure about this. It is not crops we are valuing, but the unexhausted manures. Who took the barley crops ?

“MR. MARTIN.—They took it, my lord.

“MR. WALKER.—How could we get barley on the 24th March ?

"THE WITNESS.—It was under barley in June, when I saw it—of that I am certain.

"THE CHIEF JUSTICE.—I may ask who is in possession of the farm now?

"MR. WALKER.—The Duke is, my lord.

"THE CHIEF JUSTICE.—And who sowed the barley?

"MR. WALKER.—It was not sown till after the farm was given up, for aught we know.

"THE CHIEF JUSTICE.—You see, Mr. Robertson, we are considering the value of manures left unexhausted there in March, and not the value of growing crops in the middle of June.

"THE WITNESS.—It would have made no difference. I can form an opinion as well one way as the other.

"THE CHIEF JUSTICE.—What they did to it since I don't know; but the question I have to try is not the condition of the land on the 15th of June last, but what was the unexhausted value of manures remaining on the 25th March previous.

"THE WITNESS.—And I say, my lord, that in my opinion the unexhausted manures and tillages in these fields, 7, 8 and 9, are worth £9 an acre, and after that £6 an acre more."

Now, the fields, in respect to which this evidence was given, were within a short distance of the town of Athy, and the growing barley could be seen by any one who wished it. The witness said he had

seen it ; I saw it, and ascertained, as was afterwards proved by the Duke's bailiff, that 105 bags of artificial manure had been put in by him with the barley. Yet the importance of this fact was altogether ignored by the witness.

It was obvious that the growing crop was made up of three factors :—

1. The natural produce of the soil and season.
2. The unexhausted manures left by the out-going tenant.
3. The increase produced by the artificial manures applied by the landlord.

The appearance of the crop on July 26 was that of by no means a large one ; and if the sum of £9 per acre were the value of the portion due to the unexhausted tillages and manures, little, if any, would remain assignable to the natural produce of the soil and season, and to the nearly 4 cwts. of artificial manure per acre, which were directly applied for the crop. Yet, beyond this, a further £6 per acre was claimed in respect to the next succeeding crop !

These two examples are sufficient to show that the evidence adduced erred in two important respects. It was both too minute, and not minute enough. If the object were to form a moderately correct estimate of the value of the unexhausted tillage and manures of each separate field, much essential evidence was omitted. If it were to deter-

mine the value of the unexhausted fertility of the farm as a whole, the discussion of evidence as to the special treatment of each field was unnecessary, and simply diverted attention from the real question at issue.

Let us now suppose that one or more persons, conversant with both scientific and practical agriculture, had been deputed to ascertain the state of fertility of the farm in 1873, when given up to the landlord, compared with that in 1853, when he let it on lease for 20 years, and to determine whether any, and, if so, what compensation was due to the outgoing tenant for unexhausted tillages and manures. What would have been the proper course of inquiry?

First, what was the condition of the farm in 1853, when let on lease for 20 years?

According to the evidence of Mr. Alexander, who was, at the time, bailiff to the Duke of Leinster, and cultivated the farm for 10 years prior to 1853, the whole of the farm had been sub-soiled 15 inches deep during that period. About 14 acres had only been brought into cultivation just prior to the commencement of the term of lease, in 1853, but the remainder he farmed on the five course rotation of—

One-fifth—Roots,

One-fifth—Barley (sown down with seeds),

One-fifth—Meadow,

One-fifth—Pasture,

One-fifth—Oats.

The roots were manured with from 25 to 30 tons of dung, and 3 cwts. of Peruvian Guano, per Irish acre. The roots and hay were all consumed on the farm, and no expense was spared in the cultivation during the 10 years it was in hand. It would appear, however, that but little purchased food had been used. The tenant, on entry, in the Autumn of 1853, received the growing root-crop, a rick of hay, 30 stucks of oats, and all the straw and manure.

These, then, were the conditions under which the farm was entered upon in the Autumn of 1853.

The farm was occupied for the first 11 years by Alexander Dodds, the original lessee; then for 3 years by his successor, James Cameron; and, finally, for 6 years, from 1867 to 1873, by Mr. Trye.

There can be no doubt that the condition of the land in 1867 was greatly deteriorated, compared with that in 1853. But, Mr. Trye being virtually the assignee of the original lease, the question at issue in the trial was—not the condition of the farm compared with its state in 1867, when he entered upon it, but with that in 1853, when the term commenced.

Let us now consider what were the conditions under which the farm was given up by Mr. Trye at the expiration of the term in the Spring of 1873?

An inspection in July, 1873, showed about 28 acres of barley, which had been put in by the landlord, with artificial manure, and promised a fair,

but by no means a heavy crop. There were about 30 acres, of which about one-third had been ploughed in the winter, but was very foul. The remainder had not been touched since the removal of an oat-crop, and was also very foul, with many self-sown oats growing amongst the weeds. A small field, perhaps 6 acres, was in roots, which, like the barley, had been put in by the landlord. The remainder of the farm was in grass. The hay was still in the fields, so that some estimate of the crops could be formed; and it was quite evident that the grass was the worst where it had been the longest laid down.

An examination of the soil and sub-soil, the latter being very light and stony, showed that the farm was more suited for tillage than for pasture, and led to the conclusion that manures generally, and especially soluble artificial manures, would wash out very rapidly.

First, as to "tillages," independently of manures, in 1853 and 1873:—

The term was from Spring to Spring. The tenant did not, however, enter until the autumn in 1853, but the farm was given up in the Spring 1873.

In 1853, the landlord had put in the roots, and the incoming tenant received the crop. In 1853, the area under roots was nearly one-fifth of the whole; but, in 1873, the land left in a fit state for roots amounted to only about 6 acres. Of the

remainder of the fallow land, only about one-third had been ploughed up by the out-going tenant, and the whole was extremely foul. Lastly, on this point, more than double the area was under grass in 1873 than in 1853; indeed, more than half the farm was left in grass by Mr. Trye.

From this comparison, any practical farmer would be able to form an opinion whether the out-going tenant had any claim for compensation for unexhausted *tillages*, when he gave up the farm in the spring of 1873.

Second—What is the result of the comparison of the condition of the farm in 1853 and 1873 in respect to unexhausted *manures*?

The following is the account given in by Mr. Trye, of the purchased cattle food and manures which he had used:—

From	To	Oatcake, Meal, and Feeding Cattle			Artificial Manures		
		£	s.	d.	£	s.	d.
1867, March 25, -	1868, March 25,	—			150	0	0
1868, March 25, -	1869, March 25,	110	0	0	61	10	0
1869, March 25, -	1870, March 25,	38	0	0	80	0	0
1870, March 25, -	1871, March 25,	179	0	0	28	0	0
1871, March 25, -	1872, March 25,	18	0	0	41	10	0
1872, March 25, -	1873, March 25,	110	0	0	86	0	0
TOTAL, -		455	0	0	447	0	0
Average annual, -		91	0	0	74	10	0

It has been already said that but little, if any,

purchased food had been employed during the last few years prior to 1853. According to the foregoing account, however, during the last five years of Mr. Trye's occupation, he expended an annual average of £91 on "oilcake, meal, and feeding cattle." The meaning of the term "feeding cattle" is not explained. If it refer exclusively to purchased food, the whole of the expenditure should be taken into consideration in Mr. Trye's favour; but if the sums named include the value of home-grown roots and hay, and other matters incident to "feeding cattle," it would be quite otherwise.

Mr. Alexander stated that, during the period of his occupation, prior to 1853, he applied 3 cwts. of guano per Irish acre, or bones to the same value, for the root crop. Hence, it may be inferred that the expenditure of the Duke of Leinster for artificial manures did not exceed about £50 per annum. The balance in favour of Mr. Trye would thus be about £25 per annum for purchased manures, or a total of £115 10s. per annum for purchased food and manure together—that is, provided the sums given in the foregoing account refer to purchased food alone.

From what has already been said as to the action of different manures, and of the difficulty of determining the duration of their influence, and consequently the proportion of the original value that will remain unexhausted from year to year, it is obvious, that the difficulty is much enhanced if, as

in the present instance, nothing is known of the composition of the purchased foods, and but little of that of the manures employed. With, however, a soil and subsoil so little retentive as were those of the farm in question, it is safe to conclude that manures generally would be exhausted comparatively quickly, and that the influence of their unexhausted residue would, in few cases, be perceptible for more than a year or two after the application. Indeed, two persons of equal experience and candour might differ widely in the opinion they would form on the point, upon the evidence afforded by the foregoing statements.

Still, according to the evidence, it is clear that Mr. Trye imported, annually, much more of both cattle-food and direct manures during the last five years of the lease than had been done by the Duke of Leinster prior to the commencement of the term. So far, therefore, Mr. Trye's mode of farming undoubtedly tended to improve the condition of the land, and to accumulate within it a greater store of unexhausted manure.

This condition of things was, however, entirely reversed by the procedure of Mr. Trye during the last two years of the lease. Thus, it was proved that he sold off the farm the whole of the manure produced during the winters of 1871-2, and 1872-3; and as it was stated that almost the whole of the purchased foods were consumed in the yards, the

manure produced from them would, of course, be almost wholly lost to the land. It was further proved, that about £50 worth of roots were sold off the farm.

Any practical farmer would admit that the sale of the home-made manure for two years in succession, and of £50 worth of roots from a holding of the limited area of that in question, would be a most serious drain upon the resources of a light-land farm ; and I think few would say that, under such circumstances, the outgoing tenant had any claim to compensation for unexhausted *manures*.

It may even be fairly questioned whether, upon the facts adduced, the decision of experienced and candid arbitrators would not be, that, in respect to both *tillages* and *manures*, the farm was in a worse condition when given up in 1873, than when entered upon in 1853.

ROTHAMSTED, ST. ALBANS,
January, 1874.

κ

